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Net positivity perspective of renewable fuel production impacts on climate and resource consumption – a case study

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Tiivistelmä

Monet yritykset ovat jo laskeneet tuotteilleen tai toiminnalleen jalanjäljen, mutta kaipaavat menetelmiä positiivisten vaikutusten esittämiseksi. Positiivisia vaikutuksia voidaan mitata kädenjälkimallilla, joka kuvaa kaikki yrityksen aikaansaamat positiiviset vaikutukset. Jalanjäljen ja kädenjäljen avulla voidaan laskea yrityksen nettopositiivisuus. Jalanjälki- ja kädenjälkimenetelmiä tutkittiin tässä tapaustutkimuksessa tuotteen avulla ja tuloksia verrattiin samankaltaisiin laskelmiin ja tutkimuksiin vastaavuuden määrittämiseksi.

Tässä työssä käytettiin hybridielinkaarianalyysiä hiili- ja materiaalijalanjäljen laskemiseksi tapaustuotteena toimivalle uusiutuvalle dieselille. Tarkoituksena oli testata antaako tämä nopea ja suoraviivainen menetelmä samankaltaisia tuloksia kuin perinteinen prosessielinkaarianalyysi. Hybridimenetelmä seurasi elinkaarianalyysin rakennetta ja sisälsi kaikki ylemmän tason vaikutukset laskettuna ympäristölaajennetulla panos-tuotos -analyysillä sekä suorat päästöt valmistuksesta ja käytöstä. Hybridimenetelmällä laskettu tuotteen hiilijalanjälki oli hieman suurempi kuin tuotteelle aiemmin prosessielinkaarianalyysillä laskettu hiilijalanjälki. Tämä johtui hybridimenetelmän laajemmasta systeemin rajauksesta.

Kasvihuonekaasupäästöihin ja materiaalinkulutukseen liittyvät positiiviset vaikutukset arvioitiin kädenjälkimenetelmällä, johon sisältyy suora ja epäsuora kädenjälki. Suora kädenjälki koostuu vältetyistä kasvihuonekaasupäästöistä ja materiaalin kulutuksesta, kun tutkittu tuote valitaan Business-as-usual (BAU) -tuotteen sijaan. BAU -tuote oli tässä tutkimuksessa fossiilinen diesel. Epäsuora kädenjälki koostuu positiivisista vaikutuksista, joita yritys saa aikaan oman pääprosessinsa ulkopuolella. Epäsuoraa kädenjälkeä ei voitu tässä tutkimuksessa ottaa mukaan laskuihin johtuen positiivisten vaikutusten huonosta laskettavuudesta ja tulosten epätarkkuudesta verrattuna suoraan kädenjälkeen. Kädenjälkilaskennan tulos oli, että tutkittu tuote on ympäristön kannalta parempi valinta kuin BAU -tuote.

Nettovaikutukset laskettiin nettopositiivisuusmenetelmällä. Kädenjälkien tulokset vähennettiin jalanjälkien tuloksista erikseen kasvihuonekaasupäästöille ja materiaalin kulutukselle. Nettopositiivisuuslaskennassa käytettiin ”standard perspective” oletusta, jossa yrityksen oletetaan olevan jo olemassa. Tuloksena saatiin, että tutkittu tuote on sekä kasvihuonekaasupäästöiltään että materiaalinkulutukseltaan nettopositiivinen. Tämä tarkoittaa, että vaikka edelleen tuotteen elinkaaren aikana aiheutuu nettovaikutusten tarkastelussa kasvihuonekaasupäästöjä ja materiaalin kulutusta, olisi ympäristön kannalta parempi korvata BAU tuote tutkitulla tuotteella.

Avainsanat Elinkaarianalyysi, Ympäristölaajennettu panos-tuotos -analyysi, Hybridielinkaarianalyysi, Jalanjälki, Kädenjälki, Nettopositiivisuus, tapaustutkimus, uusiutuva diesel

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Abstract of master's thesis

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Abstract

Many companies have already calculated the footprint for their products or operations but would like to be able to communicate more about the positive effects of their operations. The positive aspects can be measured with the handprint concept including all positive impacts that the company is responsible for. With the help of the footprint and the handprint, the net positivity can be calculated. These methods were tested in this case study with a case product and the results were compared to similar calculations or studies to qualify them.

This study used hybrid life cycle assessment method to calculate the carbon footprint and material footprint for a case product that is renewable diesel. The aim was to test whether this quick and simple method provides similar results compared to the traditional process life cycle assessment (LCA). The hybrid method is following the LCA structure and includes all upper tier impacts calculated with the environmentally extended input-output analysis (EE IO) model and the direct emissions from the production and use. The result of the carbon footprint calculated with the hybrid model, was slightly larger than the already existing footprint calculated with the process LCA method due to the wider system boundary of this study.

The positive effects regarding the greenhouse gas (GHG) emissions and material use were assessed with the handprint method that includes the direct and indirect handprint. The direct handprint is formed from the emissions and material consumption that is avoided by using the case product instead of the BAU product, which in this study is fossil diesel. The indirect handprint consists of the positive impacts the company is producing outside the main processes. These impacts could not be included in this study due to the imprecise positive impacts that could not be calculated with the same accuracy as the direct handprint. The result was that the case product is better for the environment than the baseline BAU product.

The net impacts were calculated with the net positivity method. The handprint values were subtracted from the handprint values separately for the GHG emissions and the material use. The "standard perspective" for the method was used and the assumption was that the company already exists. As a result, the product was net positive regarding both the GHG emissions and the material use. Based on this study, the case product is net positive, even though there are net emissions and net material usage during the life cycle and it would be better to replace all the use of the BAU product with the use of the case product.

Keywords Life cycle assessment, Environmentally extended input-output analysis, Hybrid life cycle assessment, Footprint, Handprint, Net positive, Case study, renewable diesel

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Magda Horváth

Contents

List of Abbreviations

BAU	Business-as-usual, the so called "normal" way of executing operations in an organization
CF	Carbon Footprint, all carbon emitted in the life cycle of a product or a service
CLT	Cross-laminated Timber, a thick panel of wood made by gluing lumber together in a 90-degree angle
CTO	Crude Tall Oil, Pine oil that comes as a waste from the production of paper
DMC	Domestic Material Consumption, all the materials used by an economy
DMI	Domestic Material Input, materials that are taken into use in the economy
EE IO	Environmentally extended input-output analysis, monetary based input-output analysis with environmental extensions to cover environmental impacts of actions
GDP	Gross Domestic Product, the market value of all products and goods produced in a certain time period
GHG	Greenhouse gas, the gases strengthening the greenhouse effect
GWP	Global Warming Potential, describes the warming potential of greenhouse gases in the next 100 years (GWP100)
HF	Hidden Flows, natural materials that are moved or processed during the deployment of the DMI materials and that are not taken into the use of the economy
LCA	Life cycle analysis, a method to analyze the impacts of the whole life cycle of a product
MF	Material Footprint, the sum of the masses of all the materials used to create a product
MFA	Material Flow Accounting and Analysis, a measuring tool for indicating the flows of material extraction, trade and consumption
MI	Material Intensity, the amount of material used (in kg) to produce one kilogram of the product
MRIO	Multi-region input-output analysis, distinguishes production technologies between different regions and perceives these in the effects this has to the economy
NR	Natural resources
TMC	Total Material Consumption, includes only the materials that were actually used
TMR	Total Material Requirement, takes into account all the material, even the one that is left unused in the end. Consists of DMI and HF
ZW	Zero Waste, a concept based on waste hierarchy and targeting in eliminating waste by change of design

1. Introduction

1.1 Background

Our common planet Earth is a limited space where a limited amount of natural resources is available to the humankind. At the moment these natural resources are not used sustainably, and they will not last for very long. The planetary boundaries introduced by Rockström et al. (2009) illustrate the alarming situation in Figure 1. Biodiversity loss, disturbance of nitrogen cycle and climate change are the problems that we must face most urgently, as they have exceeded the green sustainable limit of our planet. In this study, the planetary boundaries have inspired the work to focus on creating better ways of easily calculating and assessing the effects of consumption on the climate and the use of materials.

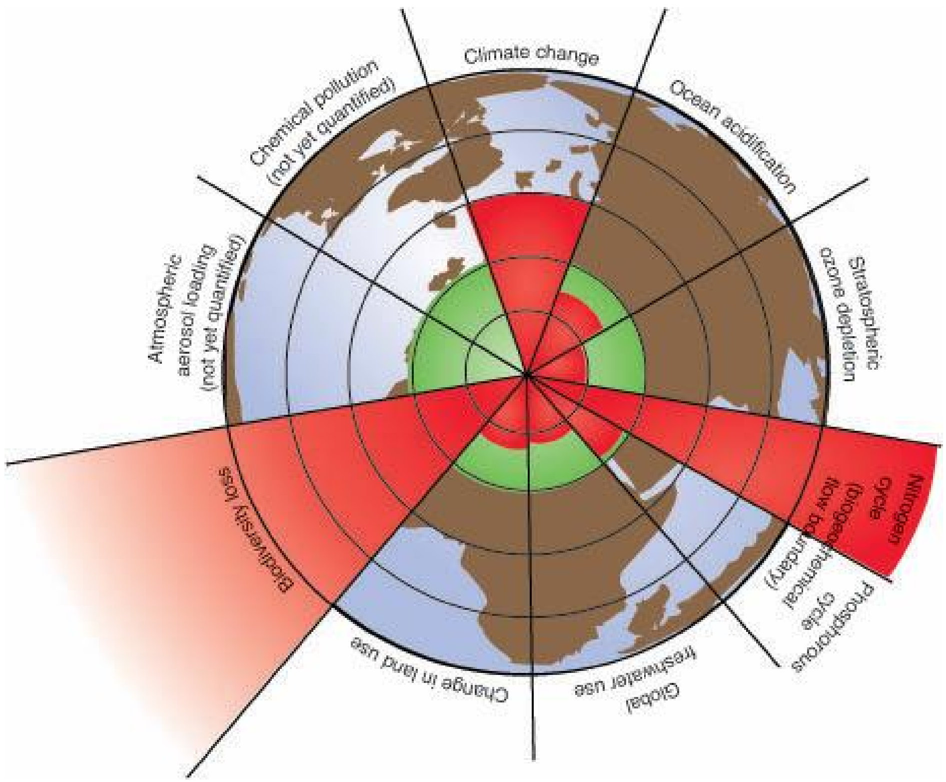

Figure 1. Planetary boundaries. The inner green circle is illustrating the safe operating space and the red sectors are illustrating the situation in different categories. (Rockström et al., 2009) (credit: Azote Images/Stockholm Resilience Centre).

The planetary boundaries are just one indication of the alarming situation our planet is facing. Different indicators, such as the Earth Overshoot Day (Earth Overshoot Day, 2019), show that the current state is not sustainable and something needs to be done. It is also necessary to understand the underlying concepts related to the theme to know, which basic measures are important. Zero waste as a concept is introduced in the theoretical foundation. A starting point for all environmentally sound operations is that the economy is supporting it. Thus, for example circular economy and zero waste are concepts that need to be followed for the more precise actions to be valuable.

Products and services are currently chosen more and more based on their sustainability and environmental impacts (Pajula et al., 2017). Consumers are more concerned about their consumption behavior and are interested in the effects that their choices have on the environment. Because of this, companies are also more interested in ways of producing reliable information about the environmental effects of their products, the whole company and their operations. The information is also needed for the internal design processes and tuning of operations to achieve the most competitive products and services in the changing consumer markets.

The more precise actions chosen to be assessed in this study are the concepts of the footprint and handprint that are based on the life cycle assessment (LCA). With the help of the footprint and handprint, the net impacts and potential net positivity can be calculated. With these methods it is possible to improve the environmental efficiency of products and operations in an economy that follows the larger underlying concepts such as circular economy and zero waste. The environmental impacts of products and operations can be assessed in a way that produces the needed information for the company and that can be also communicated to the customers.

The footprint as a concept is already scientifically accepted and there are many case studies and scientific guidelines for the use of the concept (Wiedmann, 2009). Many companies have decreased their footprints already to the minimum and cannot achieve any more positive impacts with the reductions. With the handprint concept, additional positive effects can be identified. (Grönman et al., 2019). There is still a need for new methods to calculate handprints because of the lack of standardized methods (Behm et al., 2016).

The focus of this study was on the case company UPM Biofuels, providing the case product assessed in this study. The case company was looking for an assessment of carbon and material footprint of their product, carbon and material handprint and the net positivity.

1.2 Research questions and aims

The aim of this study was to test a lighter version of the full-length life cycle analysis that could be done with less time and expenses and still include the same scope. Another aim of this study was to follow the LCA process for the calculation of the handprint and provide a case example of the calculation. More this kind of studies are needed to identify the best practices for the calculations and to pinpoint the weaknesses of different calculation methods. With the footprint and the handprint, it was then possible to calculate the net positivity. There is also a need for more case studies of net positivity since the whole concept is very new and no scientific case studies have been done yet. The research questions are tightly following these aims:

1) Does the hybrid life cycle assessment-based footprint calculation give similar results as process LCA for the case product?
2) What is the handprint of the case product?
3) What are the net impacts based on the footprint and handprint assessment?

2. Theoretical foundation

2.1 Environmental Footprint

This study uses consumption-based environmental accounting to assess the carbon and material footprints. The full and scientifically accepted instructions on counting footprints are presented in PAS 2050 (2011) standard and in the GHG Protocol (2011). The footprint method is established and described in detail by Wiedmann (2009). The footprint method is still not a completely satisfactory way to capture all the nuances of human actions towards the environment (Huijbregts et al., 2010; Owen, 2017) but footprints could potentially be the solutions for describing the complex environmental problems (Ridoutt and Pfister, 2013). In practice, there are different methods used for calculating the footprints.

The environmental footprint in this study consists of the material footprint (MF) and the carbon footprint (CF). The CF is not a valid tool for explaining the whole environmental burden of human actions because of overemphasized reductions in carbon emissions by manufacturers who may shift the harm to other areas such as toxicity (Laurent et al., 2012). Therefore, also the material footprint is included in the environmental footprint. The different footprints are not substitutes but complement each other (Fang et al., 2014).

The footprint counting includes all upstream impacts that have occurred before the product is ready (Lenzen et al., 2007). The common way to measure the footprint is to use an area as the unit. In many cases it is though clearer to use masses instead of areas to avoid a lot of unit changes and therefore errors. (Wiedmann and Minx, 2008).

In the next sections the theory of the material footprint and the carbon footprint are described separately. The details of the calculation processes are described in Section 3.4.2a.

2.1.1 Carbon footprint

A carbon footprint includes all greenhouse gas (GHG) emissions emitted during the life cycle of a product or a service. There are many definitions for carbon footprint and the one defined in PAS2050 (2011) is that the carbon footprint describes the GHG emissions of a product or a service generated during the life cycle per mass or other product unit. The footprint could also be called climate footprint, but the CO_2 equivalents are used and therefore "carbon footprint" is considered to be an adequate term for the footprint.

The most important greenhouse gases are CO_2, CH_4 and N_2O and they are converted into CO_2 equivalents by using the factors given by IPCC (2007) that are describing the warming potential of these gases during the next 100 years (GWP100) (Hendrickson et al., 2006; IPCC, 2007; Wiedmann, 2009). The carbon footprint is based on these measures.

Carbon footprints can be calculated according to the official standards either with a process life cycle analysis (process-LCA), a bottom-up method, or an environmentally extended input-output analysis (EE IO), which is a top-down method (Wiedmann and Minx, 2008).

The carbon footprint as a concept has received some criticism, which concerns mainly the need for large amount of very specific data that cannot always be found. When there is a requirement for detailed data, the model is not working optimally with insufficient data and the outcomes can be severe underestimates. (Chakraborty and Roy, 2013; De Benedetto and Klemeš, 2009). This problem can be averted with the use of the input-output method that includes all the upstream emissions with only the information of material costs. Another criticism of carbon footprint is concerning the inaccurate accountability of the amounts of carbon sequestration the land and forest area can provide (Fang et al., 2013). These land areas are not always considered in the calculations and the land use changes are overlooked even though they may have serious impacts on the climate (Fang et al., 2013).

The carbon footprint of a product is counted for the whole life cycle, whereas for other activities or processes the time of one year is usually used. This is because one year is in national and corporate financial accounting a standard time frame. (Minx et al., 2009). A more detailed explanation of the calculation of the carbon footprint can be found in Section 3.4.2.

2.1.2 Material footprint

The current human population is using the highest amount of raw materials in history (Wiedmann et al., 2013). The fundamental problem in the way our society is using materials is the change in the natural flows of materials in ecosystems. This is inevitable, but the current pace of change is harming even the life-sustaining functions and the services our ecosystem is providing. All used material ends up as waste in the current linear economy and by reducing the use of materials it is possible to affect the amount of waste as well. (Lettenmeier et al., 2009). Products and services using less materials are more ecologically efficient than more complex products (Lettenmeier et al., 2009) constructed of non-separable composites that could be even toxic in the first place.

The material footprint of a product is the sum of the masses of all the materials used to create a product (Lettenmeier et al., 2009). A simplified example of the material footprint could be a wooden table. All the wood cut, and other materials and fuels used to manufacture a wooden table create the material footprint.

MFA (Material Flow Accounting and Analysis) is the most important tool to measure and indicate the flows of material extraction, trade and consumption (Lutter et al., 2016). The different material flows can be described in multiple ways. This study adopts the terminology used by Wiedmann et al. (2013) and the latest Eurostat Economy-wide material flow accounts Handbook (Eurostat, 2018). In addition to these sources, some terms are from Seppälä et al. (2009) due to the fact that the calculations are partly based on the coefficients from the report.

Domestic Material Consumption (DMC) is all the materials used by an economy. This means that all domestic raw materials and all physical imports, from which all physical exports are subtracted, are counted together. The upstream raw materials of nondomestic imports and exports are not included in DMC and therefore DMC is not comprehensive enough as an illustration of a material footprint. As a synonym for MF the term Raw Material Consumption (RMC) can be used (Eurostat, 2018; Giljum et al., 2014; Wiedmann et al., 2013). Eurostat (2018, p. 118) describes the RMC in following words: “represents the total amount of extracted raw materials needed to produce the goods and services consumed and invested by residents”. Wiedmann et al. (2013, p. 1) describe RMC as “global allocation of used raw material extraction to the final demand of economy”.

This means that RMC includes both the domestic and foreign extraction of materials (Eurostat, 2018).

Two older terms used in MFA are Total Material Consumption (TMC) and Total Material Requirement (TMR). TMR takes into account all the material, even the one that is left unused in the end, while RMC includes only the materials that were actually used. (Schmidt et al., 2019). In the same way as RMC, TMC includes only the materials that were actually used (Wiedmann et al., 2013). In this study, MF is calculated based on TMR values that are used by Seppälä et al. (2009). The description of TMR in their report is based on earlier Eurostat (2001) report. TMR consists of Domestic Material Input (DMI) and Hidden Flows (HF) (Eurostat, 2001). HFs are natural materials that are moved or processed during the deployment of the DMI materials and that are not taken into the use of the economy. These could be for example erosion of agricultural land, unused logging waste and waste land from mining and construction. (Seppälä et al., 2009). In addition to the different domestic and foreign material flows, the consumption-based MF includes all materials in the trade balance regardless of their leaving the country or not. For example, process waste and auxiliary material flows are not leaving the country. (Wiedmann et al., 2013).

In high-income countries, such as Finland, the material consumption increases along with the gross domestic product (GDP). The rate of increase is 10% for GDP and 6% for the national material footprint during the same time. When GDP increases, countries tend to move the production from domestic to nondomestic, which increases the material consumption and therefore the material footprint. This means that their DMC/capita is much smaller than their MF/cap. The lowering DMC seems to indicate good development, but economic growth and environmental emissions are not decoupled. The fast growing economies, such as China and India, have managed to decouple their GDP from both DMC and MF. (Wiedmann et al., 2013). The GDP/DMC has been described as the “resource productivity” that is an indicator of sustainable growth (European Commission, 2011) but another indicator used is “total resource (or material) productivity”, which includes the materials removed from nature to create a service or a product and the hidden flows (Bringezu and Bleischwitz, 2009).

2.2 Environmental Handprint

The term Handprint was launched for the first time in 2007 in The 4th International Conference on Environmental Education (Centre for Environment Education, 2007). It was created to be used for measuring and teaching sustainability (Centre for Environment Education, 2016) and to function as a communication and marketing tool (Grönman et al., 2019). It can be applied for products, processes, individuals, organizations and companies (Behm et al., 2016). The handprint is not a purely environmental way of measurement and can also include social aspects (Behm et al., 2016) such as women’s rights or education. The handprints can be calculated for different aspects, such as material use, carbon, water and social issues. These are same aspects that the footprint can be calculated for.

The concept of handprint is new and thus there are no standards or standardized methods to calculate it. Also peer-reviewed literature on the topic is thin. Research and validated methods are needed to accomplish a comparable way for measuring the handprint. The core idea of the concept is to make positive changes and create new ideas and encourage other actors for positive action. (Behm et al., 2016). Different researchers and industries have developed the handprint calculation simultaneously and to different directions with different scopes and definitions. Therefore, there is a need for clarification and harmonized guidelines. (Grönman et al., 2019). This study was motivated by the need to develop the concepts of the handprint and the footprint and their consolidation to calculate the net positivity of the case product.

The main difference between the footprint and the handprint is related to the perspective of seeing problems. The footprint measures all the negative aspects and the handprint the positive ones (Biemer et al., 2013). One could say that they are the opposites of each other. Table 1 presents a comparison of the key aspects of the two.

Table 1. The differences between the concepts of Handprint and Footprint following Biemer et al. (2013)

Handprint thinking	**Footprint thinking**
The good we do	The harm we cause
Unlimited potential	Limited resources
Recover/Restore	Reduce/Reuse/Recycle
Influence/Educate/Inspire	Admonish
Count accomplishments	Measure quantities
Appreciate/Celebrate	Calculate
Advocate protection	Resist destruction
Entrepreneurism	Problem solving

Despite the differences in the perspective, the calculation of the footprint and handprint is similar and should be based on the whole life cycle (Behm et al., 2016) and be done according to the LCA framework (Grönman et al., 2019). In practice there is the same danger of double counting in the handprint calculations as is in footprint calculations and it needs to be considered carefully (Norris, 2013b).

As was stated, there is no standardized method to calculate the handprint but there are several rules and guidelines for the calculation. According to Grönman et al. (2019) the calculation should be based on the LCA method to make the handprint comparable with the footprint. Therefore, the process of calculating the handprint follows the same methodology as the footprint. A more technical description of the handprint is: the amount of avoided emissions by using a better technology (Alhola et al., 2015; Norris, 2015) or acting outside of the process to create positive impacts (Norris, 2015, 2013a). This means that there are two ways to increase the handprint, the direct handprint and the indirect handprint. Direct handprint includes preventing or avoiding the occurring negative impacts from producing and/or using the product and indirect handprint includes creating positive outcomes that would not otherwise have happened (Behm et al., 2016; Norris, 2015). An example of an indirect handprint could be for example increasing the carbon sinks by afforestation.

The direct and indirect handprint are not competing but complementing each other. The prevented negative impacts are compared to the business-as-usual (BAU). The comparison can be challenging to do in such a way that different calculations would be commensurable (ICCA and WBCSD, 2013). One way to define BAU is to see if the demand of next year is met with the product models of last year and produced using the methods of last year (Norris, 2013b). Another way to define BAU, is to see that both the BAU product and the studied product 1) provide the same function 2) are used for the same purpose 3) are available and used in the same region and period of time 4) are assessed in a consistent manner (Grönman et al., 2019). The Innovation-Relevant Time Horizon is the time when the new product is still an innovation and is sold as the new product and the time depends on the use time of the product (Norris, 2015).

According to Norris (2015) there are three ways to create a handprint for a product: 1) improving the performance of an existing product so that in the future the improved product fulfills the demand 2) coming up with a new product that is better than the other ones in the market and will replace them 3) increasing the demand of an existing product so that the poorer products will lose some of their market share. These are merely alternative ways of displaying the previously discussed direct handprint.

It is important to distinguish minimizing the footprint and increasing the handprint. Grönman et al. (2019, p. 1061) defined the carbon handprint as: "A carbon handprint is the reduction of the carbon footprint of a customer or customers.". This is not conflicting with the earlier definitions because it is merely stating that the footprint of the customer is reduced. The minimization of the footprint of a product is not increasing the handprint but avoiding the footprint of customers, which would occur by using the product or service increasing the handprint of a company. Also reductions in footprints due to new regulations or laws are not counted as increasing the handprint, only voluntary and intentional actions towards better are counted. (Norris, 2015).

While the handprint concept can be used for products, processes, individuals, organizations and companies (Behm et al., 2016), it is not possible to calculate a handprint for a single product (Norris, 2015). A product itself cannot do any positive changes regarding the environment, only an actor or an entity can create a handprint (Norris, 2015). Grönman et al. (2019) argued that a handprint could be calculated for a product, while the direct handprint is calculated as the savings of emissions from using the improved product. The handprint still is allocated to the actor from whom we can say that the positive impact would not have happened without the contribution of an actor. The efficiency of the handprint is also related to the number of actors creating it. If there is only one actor responsible for creating the handprint, it is most effective. (Norris, 2015).

With the handprint approach a company can take a leading and active role in tackling the climate change problem and show example to other companies by supporting best practices and products (Behm et al., 2016). The handprint calculation helps companies to actually reduce and manage their climate impacts (Grönman et al., 2019). The induced positive actions in other actors with the handprint and generating positive effects is called the ripple effect. Positive ripple effects generate more positive ripple effects. (Norris, 2015). It is studied that in long term increasing the handprint can be economically profitable. When investors realize the potential of the company and decide to invest, the short term payments are worthwhile. (Delmas et al., 2004). Using the handprint as a tool could be a competitive advantage for a company that wants to be a forerunner (Behm et al., 2016).

2.3 Net positivity

Similar to environmental handprint, net positivity is a new concept, and thus lacks a common definition. The reasons for creating the concept of net positivity are highlighted by Behm et al. (2016). All actions cause a footprint of some magnitude due to the inevitable emissions. For example, even riding a bike causes emissions because the bicycle must be first made and then in the use it wears out and must be repaired or some parts must be changed. This kind of thinking leads to the idea, that it would not be good for the environment to do anything. To modify this thinking, there is a need to identify positive outcomes from actions, in other words, the handprint needs to be grown preferably to be larger than the footprint, which then leads to a net positive outcome. When the environmental handprint is larger than the environmental footprint, the company/action is net positive (Behm et al., 2016).

The effort of being net positive is not a short investment. It is closer to a marathon as was stated by Aeron-Thomas and Le Grand (2015). No company can achieve net positivity by merely calculating the footprint and handprint and comparing them to each other. There always needs to be measures for decreasing the footprint and increasing the handprint to reach the goal of net positivity. It is though not possible to measure every single aspect of the actions but that should not stop people from continuing with the process though (Aeron-Thomas and Le Grand, 2015).

Aeron-Thomas and Le Grand (2015) presented 12 net positive principles that guide the transition towards net positivity. These principles are presented in Table 2. When the 12 principles are followed, it can be assumed that all different actors are operating in the same manner.

Table 2. The 12 net positive principles (Aeron-Thomas and Le Grand, 2015).

1	The organization aims to make a positive impact in its key material areas.
2	The positive impact is clearly demonstrable if not measurable.
3	As well as aiming to have a positive impact in its key material areas, the organization also shows best practice in corporate responsibility and sustainability across the spectrum of social, environmental and economic impact areas, in line with globally accepted standards.
4	The organization invests in innovation in products and services, enters new markets, works across the value chain, and in some cases, challenges the very business model it relies on.
5	A Net Positive impact often requires a big shift in approach and outcomes, and cannot be achieved by business-as-usual.
6	Reporting on progress is transparent, consistent, authentic and independently verified where possible. Boundaries and scope are clearly defined and take account of both positive and negative impacts. Any trade-offs are explained.
7	Net Positive is delivered in a robust way and no aspect of a Net Positive approach compensates for unacceptable or irreplaceable natural losses, or ill treatment of individuals and communities.
8	Organizations enter into wider partnerships and networks to create bigger positive impacts
9	Every opportunity is used to deliver positive impacts across value chains, sectors, systems, and throughput to the natural world and society.
10	Organizations publicly engage in influencing policy for positive change.
11	Where key material areas are ecological, robust environmentally restorative and socially inclusive methods are applied.
12	An inclusive approach is adopted at every opportunity, ensuring affected communities are involved in the process of creating positive social and/or environmental impacts.

There are also 7 principles to guide the measurement of net positivity. These are presented in Table 3.

Table 3. 7 principles guiding the measuring of net positivity (Aeron-Thomas and Le Grand, 2015).

	Principle	**Explanation**
1	*Transparency*	Other actors can study and compare to enable emergence of the best practices
2	*Consistency*	Compare like with like
3	*Completeness*	It is better to use an estimate, even if conservative, than to leave a gap when data is missing
4	*Keep different types of impacts separate*	Employee training will not cover for deforestation
5	*Keep positive and negative impacts separate*	Positive impacts do not always compensate for negative impacts. For example, employee training vs. poor working conditions
6	*Use existing methods where possible*	For example, GHG Protocol
7	*Sharing data is vital*	Prevents double work, for example actors will not have to make the BAU calculations always from the beginning

In addition to the principles presented in Table 2 and Table 3, Behm et al. (2016) present two different perspectives that could be used as guidance in the selection of the system boundaries and how to outline the calculations. In the "standard perspective", the existence of a company is taken as given and all reductions to the total emissions of the company are counted as a positive aspect and are counted to the handprint. In some cases, even the reductions in the footprint are included in this but as was stated in the chapter of environmental footprint, it is not acceptable to calculate the reductions in footprints as an increase of the handprint. In the "contingent existence perspective", the world is better off with the company than without the company and the reductions in the footprint of the company are not counted as a larger handprint (Behm et al., 2016). To calculate with the "contingent existence perspective", the average footprints of same goods or processes are needed because if the company was better than average and would not exist, the more of the poorer options would be used (Behm et al., 2016).

Figure 2 shows an illustration of the "contingent existence perspective" net positive concept. This means the following: net impacts, regarding for example the emissions or material use, there are more positive impacts than negative. As a comparison different terms are situated on the line towards net positive. Usually the BAU methods are producing large amounts of negative impacts. The "Eco" and "Green" products and services are also producing negative impacts but not in a similar manner as BAU. If a company is carbon neutral, it is situated in between the positive and negative impacts. This means that the same amount of carbon is sequestered as is emitted to the atmosphere. The restorative and regenerative actions are something that creates more benefits and for example restores the biodiversity or regenerates carbon sink forests.

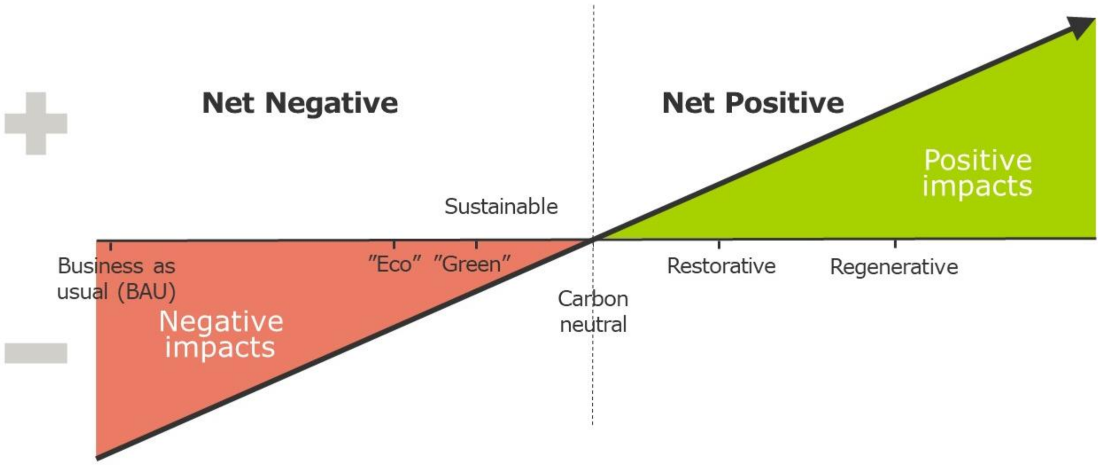

Figure 2. Illustration of net positivity with "contingent existence perspective" modified from Brown (2016).

In order to have comparable handprint and footprint, they need to be in same units to enable the calculation (Behm et al., 2016). The handprint and the footprint also need to be in the same timeframe (Norris, 2015), which usually is annual. There are two methods to calculate the annual impacts. The first is the "sales-year method" where the whole handprint is calculated for the year of purchase, which is the easier method. Another method is the "impact-year method" where the impacts are counted how they are each year. (Norris, 2015).

Aeron-Thomas and Le Grand (2015) introduced different measurement activities for net positivity. The measures are materiality, measuring impact, extrapolation, measuring outcomes, assurance and transparency. All these measures need to be followed in a study. *Materiality* refers to deciding the key material areas of the company or production. For example, a company producing wooden furniture could identify wood and energy usage as their key material areas. Every single aspect of the production cannot be measured, and thus it is important to first select the key material areas and then continue to the smaller areas. The justification of key material areas and identification of system boundaries are also important. *Measuring impact* refers to identifying how greatly the system has changed. This begins with setting the baseline of the current actions or BAU and then all the changes are compared to this stage. It is also important to consider if the effects have only shifted elsewhere, for example other countries or industries, and if there is rebound effect. *Extrapolation* is an unavoidable part of the study and several assumptions always needs to be made. It is important to take averages if there is not proper data available and always justify the decisions made. *Measuring outcomes* is allocating the positive outcomes to the right actors and figuring out how to calculate them. There is no one way above others to do this and therefore transparency in the decision making is extremely important. *Assurance* is to gain confidence in information and to ensure validness of it. For example, certificates provide assurance. *Transparency* is the key to all the calculations. It is important to be as open as possible in how the decisions are made and what the assumptions are. The transparency can be achieved for example through publications, accessibility or engagement. (Aeron-Thomas and Le Grand, 2015).

In order to gain net positivity in terms of carbon, first the carbon footprint is calculated and then the carbon footprint avoided from upstream, operations and downstream is calculated (Aeron-Thomas and Le Grand, 2015). Then the positive impacts made outside of the process (indirect handprint) are added to the avoided footprint (direct handprint) to form the full handprint. The handprint is finally subtracted from the footprint to get the net impacts.

Being net positive in terms of material use means that more material is renewed than used and the material use is responsible. The percentage of certified materials should be counted because they can be trusted to renew at least at the same pace that they are exploited. The material net positivity can be measured by material footprint, avoided material footprint and value created in upstream, operations and downstream. (Aeron-Thomas and Le Grand, 2015).

2.4 Zero waste concept

The concept of Zero Waste (ZW) aims for an economy that does not waste resources. It does not mean that there should be nothing to recycle but that nothing is sent to the landfill or waste incineration (ZWIA, 2009). The Zero Waste International Association describes the concept in their website in the following way “Zero Waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them. Implementing Zero Waste will eliminate all discharges to land, water or air that are a threat to planetary, human, animal or plant health” (ZWIA, 2009). The main target of the Zero Waste concept is not only to enhance recycling but also to restructure the society in a way that promotes better design, production and distribution to exclude the waste from the whole process (UNECE, 2011). ZW concept is in line with circular economy where all resources and materials are circulating in their own cycles and are not wasted by incineration or disposal to landfills (ZWIA, 2013). With these concepts for example the utilizing of side streams increases in necessity and should be investigated as a way of achieving zero waste and circular economy targets.

There is an excessive waste problem that is not a modern issue. The society is structured to create waste and thus actions on a deeper level are needed. (Lehmann, 2010). Waste is always a sign of inefficiency and indicates poorly planned material flows (Zaman and Lehmann, 2013). Therefore, the concepts such as circular economy and zero waste are needed and are tackling not only environmental issues but also economic issues. To actually gain improvements, a significant change would be needed in the market, which is at the moment acting as a barrier for the development of circular economy (European Commission, 2014).

The ZW concept has been used widely but there is no strict guideline for implementation and therefore the usage has varied greatly, and the concept is still in development. It is unfortunately inevitable that in our current society non-recyclable waste cannot be reduced to zero and the recycling rate cannot achieve 100%. (Zaman, 2015). Therefore, the Zero Waste concept needs to act as a target and future goal to guide the policy and action towards better and more sustainable economy even if the actual ZW goal could not be achieved in the near future.

The concept of ZW follows a hierarchy that prefers reducing and considers landfilling and incineration only as the last and worst option. This ZW hierarchy shown in Figure 3 is developed to improve the waste hierarchy and to guide the policies and strategies to support the hierarchy with the best use of materials (ZWIA, 2013).

Figure 3. Zero waste hierarchy according to ZWIA (2013).

The last options for waste management, landfilling and incineration (high temperature mass burning and pyrolysis etc.), are not acceptable according to the ZW hierarchy because they are used to dispose materials that are usually mixed wastes (ZWIA, 2013). Resource recovery from waste is essential for the concept (Zaman, 2015) and the aim of the hierarchy is to provide guidance for decision making and a method to evaluate the proposed actions (ZWIA, 2013). As can be seen from the hierarchy, the Zero Waste practices need to be conducted in every part of the product life cycle in order to achieve the Zero Waste goal (Zaman, 2015). If for example the policy is against the concept and the design is not supporting reusing, then it is impossible to carry it out. A detailed version of the ZW hierarchy can be found in Appendix 1.

The Zero Waste concept is used in this study as a guiding principle. When the goal is to achieve a well performing method to easily calculate the net impacts of a product or a company, it is essential that the underlying concepts such as zero waste and circular economy are clear during the whole process. For example, there cannot be any trade-offs in the selection of used materials due to lower costs if the reuse or repair is not possible with the material. This way it is possible to assess the true costs and benefits from the production and evaluate the environmental impacts of the production and gain information of ways to improve the process.

3. Materials and methods

3.1 Analysis steps

The analysis in this study follows the steps in Figure 4. The data is from the case company (UPM, 2019a) and from Motiva (2010), Seppälä et al. (2009) and Wuppertal Institute (2014). This data was used for the source methods and calculating the carbon and material footprints of the case product and the comparable BAU product. From the footprints a comparison between the BAU product and the case product was made to calculate the carbon and material handprints. By subtracting the handprint results from the footprint results the net positivity regarding the GHG emissions and the material use was calculated.

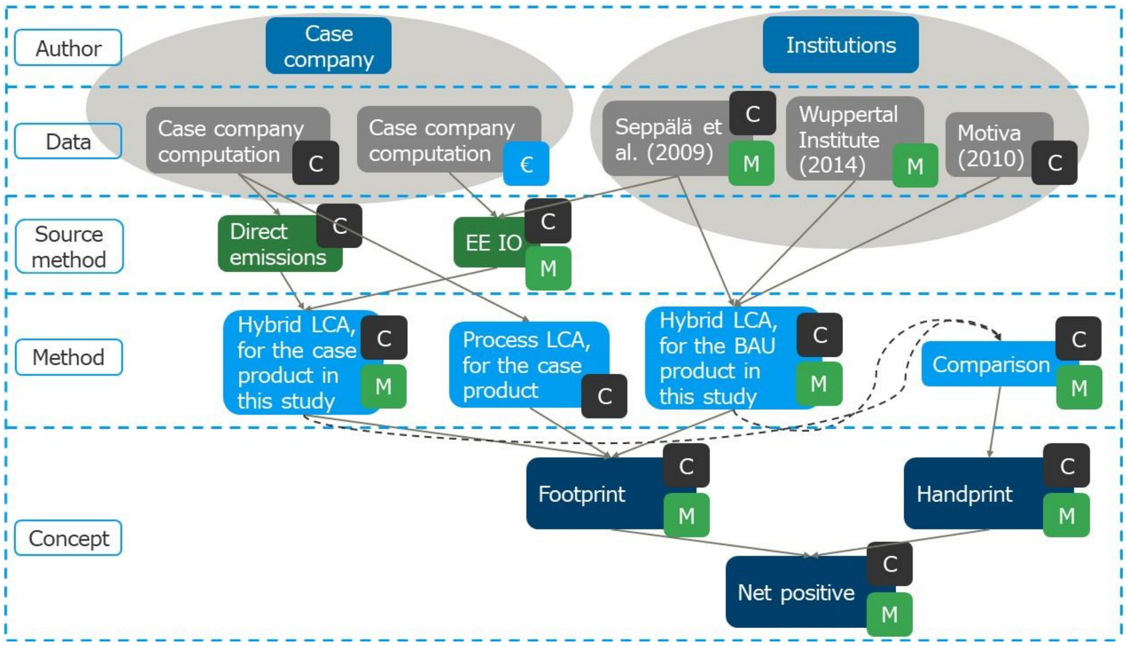

Figure 4. Analysis steps of this study. The black C-symbols represent GHG emissions and the green M-symbols the material use. The blue €-symbol represents monetary data.

3.2 Materials

3.2.1 Case company and product

The case company UPM is a major Finnish forestry industry company. The study focused on one manufacturing facility, the UPM Lappeenranta Biorefinery, where the end products are UPM BioVerno naphtha and the UPM BioVerno diesel. Part of the naphtha is used as feedstock for bioplastics and the rest as a biocomponent for gasoline. The main raw material in the production of the renewable naphtha and diesel is crude tall oil (CTO), which is a residue from a neighboring pulp mill also owned by UPM. The production of the CTO in the neighboring pulp mill is not enough for the purposes of the biorefinery and therefore CTO is also coming from other mills in Finland and abroad. From the process of the biorefinery, two different residues are formed. One of the residue products is pitch that is sold for energy production and the other is turpentine that is sold for perfume industry as an ingredient. (Aluehallintovirasto, 2011).

The major inputs and outputs are illustrated in Figure 5. In addition to CTO as the main input, electricity, natural gas, chemicals, steam and water are used in the process. Pitch and turpentine are the residues and naphtha and diesel the end products. Some waste and flue gas are generated in the process. Waste water of the process is handled in a waste water treatment plant that is serving the needs of both the pulp mill and the biorefinery. (Aluehallintovirasto, 2011).

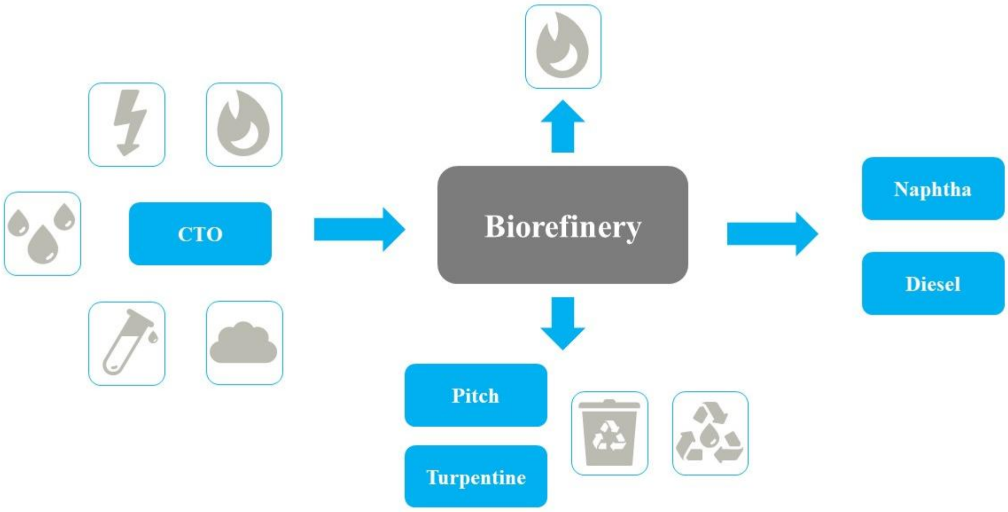

Figure 5. The material streams in the UPM Biorefinery in Lappeenranta.

The biorefinery is relatively new and a full carbon footprint for the life cycle of the product has been calculated. This carbon footprint is 80 % smaller than for the comparable non-renewable diesel made from fossil fuels (UPM, 2019b).

The corporation the case company belongs to, has forests in many countries around the world and the corporation has for example built a network of 6,000 hectare wide protected areas in Uruguay (UPM, 2019c). In Uruguay the forests are tree plantations that have been established on lands that were used for example as grazing areas before. This way the forest area in Uruguay has increased. The corporation does not transform natural forest into plantations. (UPM, 2019d). Forestal Oriental is responsible of the tree plantations in Uruguay and they have been working there since 1990. In Uruguay the corporation owns around 230,000 hectares of land from which 140,000 hectares are tree plantations and the rest is either protected area or used for other purposes such as grazing land. (UPM, 2019c). Also, in Finland since 1990 the corporation has sold or given land to the state for protection purposes or protected as a corporation about 25,000 hectares of land (UPM, 2019e). In Uruguay and Finland the forests own by the corporation form carbon sinks (UPM, 2019b).

Two types of data from UPM Biofuels were used. The confidential monetary input data was in euros and included all monetary inputs during the life cycle of the case product until the production. The monetary inputs of the construction of the biorefinery were included. (UPM, 2019a). The direct GHG emissions from the production in the year 2018 were the second set of data. The direct emissions were 11.81 g CO_2e/MJ and are not included in the monetary values. Therefore, they needed to be added into the calculations to cover the whole product life cycle. Also, the amounts of different end products, naphtha and diesel in tons were used (UPM, 2019a). For naphtha and diesel, the heating value was

44.0 MJ/kg and density 0.812 kg/l. These values were used in the calculations of the footprints and handprints.

3.2.2 Environmental coefficients

The Finnish Environmental Institute provides a national input-output model of material flows in the Finnish economy (Seppälä et al., 2009). Both imports and exports are covered, but the environmental effects of exports are not studied. The data for material flows in million euros is from 2002 and 2005 statistics from Statistics Finland (Tilastokeskus). This model is unfortunately the latest publicly available model.

Seppälä et al. (2009) added two matrices together 1) the environmental emissions: industry categories are in columns and environmental data in rows 2) economic data from Statistics Finland. The model was a semi-MRIO, which means semi multi region input-output (MRIO) analysis. Semi-MRIO distinguishes production technologies between different regions and perceives these in the effects it has to the economy (Suh and Huppes, 2005). Seppälä et al. (2009) noted that in their semi-MRIO model the imports are included trough the data from the Ecoinvent database. Due to this, the model could also be called a mixture process LCA.

The coefficients from the model by Seppälä et al. (2009) cover the emissions of the life cycle of the products until they are in the hands of the new owner. This means that the emissions from producing something from the product or using the end-product are not included in the coefficients. The coefficients are reported in kg of GHG/€ and kg of used materials/kg, which is the TMR mentioned in the Section 2.1.2. The coefficients were used to calculate the GHG emissions and material consumption of the life cycle before the production from the monetary input data of the case company.

3.3 Theory behind the method

In this study, the methodology behind the calculations of the environmental footprint and handprint was the hybrid life cycle assessment. The hybrid life cycle assessment is based on environmentally extended input-output analysis, where direct emissions from the process and the emissions from the use of the product are added to the calculations. This way, the analysis was not restricted only to the inputs and outputs but was extended to all the emissions from the process. In this chapter, the basics of life cycle analysis, the environmentally extended input-output analysis and the hybrid model are described.

3.3.1 Life cycle assessment

Before the input-output analysis is tackled, there is a need to shortly go through the basics of life cycle assessment to which the input-output method is based on. The aim of environmental LCA is to analyze the whole life cycle of a product or a process from the raw material sources to the end-of-life (Ottelin, 2016). First in the LCA process there is a need to identify the scope and goal of the analysis, then there is inventory analysis, impact assessment and then the results are interpreted (ISO 14040, 2006; ISO 14044, 2006).

In the identification of the scope and goal, a major critical part is defining the system boundary (ISO 14040, 2006; Suh et al., 2004) and the functional unit (ISO 14040, 2006). The relevancy of processes and whether they should be included in the calculations, as in being inside the system boundary, is handled in the PAS 2050 standard for products (Wiedmann, 2009). Several indicators should be used to measure what inputs and outputs are significant and should be included inside the system boundary. The processes left out of the analysis are called cutoffs and can contribute together to even bigger impacts than the ones that are analyzed. (Suh et al., 2004). The PAS 2050 standard advises that all processes that contribute to the anticipated final footprint more than 1% should be included in the calculations, also minimum of 95% of the anticipated emissions of the functional unit must be included in the calculations (Huang et al., 2009). These are slightly paradoxical requirements because first it needs to be figured how large the full footprint is to evaluate whether some process is significant enough for that calculation (Huang et al., 2009; Suh et al., 2004).

The strongest flaw of the process LCA is the truncation error (Suh et al., 2004; Wiedmann, 2009). Process LCA is seen as more detailed and specific than the input-output analysis but it also needs a lot more time and effort (Suh et al., 2004). The truncation error is formed because the system boundary has to be drawn somewhere and it is finite, thus there will be cutoffs (Lutter et al., 2016; Suh et al., 2004). The error might seem insignificant because only the assumed insignificant errors are left outside the system boundary (Ottelin, 2016) but with hybrid models it has been indicated that these "insignificant" contributions may add up to even more than 50% of the total environmental impacts (Lenzen, 2000; Nässén et al., 2007; Suh et al., 2004). The truncation error is described in more detail in Section 3.3.2.

3.3.2 Environmentally extended input-output analysis

Environmentally extended input-output (EE IO) analysis is a life cycle assessment based top-down method that can be used as a consumer-based method or production-based method (Ottelin, 2016). EE IO was originally invented by Leontief (1970), who also invented the original input-output method (Huang et al., 2009; Leontief, 1986; Ottelin, 2016). The economic input-output analysis is based on monetary transaction matrices, which have the information of transactions between economic sectors. The monetary inputs are used to produce products that are the outputs. (Ottelin, 2016). When the environmental extension of the analysis is used, environmental indicators are added to the matrices and this way the environmental burdens can be analyzed (Leontief, 1970). The EE IO method is studying the relation of economic activities such as using money for buying intermediate products and the environmental impacts of these activities. It is used to calculate the hidden upstream environmental impacts that are related to the downstream consumption. (Kitzes, 2013).

The calculation of EE IO is based on Equation (1) created by Leontief (1970):

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{f} \qquad (1)$$

where $\boldsymbol{x}$ is the total output, $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ is the Leontief inverse (industry-by-industry, M€/M€) and $\boldsymbol{f}$ is the final demand i.e. the expenditure of various consumption categories (vector) (Leontief, 1970). In the Leontief inverse $\boldsymbol{I}$ is the identity matrix (industry-by-industry) and $\boldsymbol{A}$ is the coefficient of intermediate use matrix (industry-by-industry). The columns of $\boldsymbol{A}$ give the intermediate industry outputs in M€ that is needed to produce a unit of output in M€ of another.

The environmental extension to this formula is described in the following Equation (2):

$$\boldsymbol{g} = \boldsymbol{B}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{f} = \boldsymbol{M}\boldsymbol{f} \qquad (2)$$

where $\boldsymbol{g}$ is the total emissions (emissions/kg) i.e. the consumption of resources caused by $\boldsymbol{f}$, the final demand. In the case of for example the carbon footprint, $\boldsymbol{g}$ would be the carbon footprint. $\boldsymbol{B}$ is the emission intensity i.e. the emission and resource flow-by-industry, kg/€, and $\boldsymbol{M}$ is the environmental multiplier matrix, i.e. the emission and resource flow-by-industry, kg/€. In the carbon footprint case, the $\boldsymbol{M}$ would be the GHG intensity of the consumption category. (Leontief, 1970; Mattila, 2013; Suh and Huppes, 2005).

A consumption-based inventory "counts all of the emissions required for a given sector to sell goods and services to end consumers" (Kitzes, 2013 p. 11). Another approach is a production-based inventory, which includes only the direct emissions from production (Kitzes, 2013). Due to the hybrid model used, all the emissions from the cradle to the use-phase are included. By using solely the EE IO method, the inventory would be production-based.

A product-by-product IO table describes what amount of product is needed to produce another product (Eurostat, 2008). These values are not related to the whole industries (Eurostat, 2008) as is the case in the description of EE IO in this section. Some authors such as Kitzes (2013) and Ottelin (2016) use the term EE IO for environmentally extended input-output analysis and others such as Herstein et al. (2011), MacLean et al. (2000) and Virtanen et al. (2011) use EIO-LCA, which is abbreviation of environmental input-output life cycle assessment. These terms essentially have the same meaning and in this study the term EE IO will be used.

In EE IO the input-output tables have the economic value transported between different sectors in the meso level. This way the boundary of the calculations is set to the whole economic system. Because of the magnitude of the data, it cannot be very detailed. When the EE IO model is in place, it is easy and fast to calculate with it. (Wiedmann and Minx, 2008). For sector-wide analysis, national statistics usually have the needed data for the calculations (Suh et al., 2004).

The EE IO method combines physical data of material flows with the information of the structure of the supply and flows within economies. It shows the transactions of different sectors of an economy with physical or monetary units. A key assumption in this method is that final demand is driving the material use. This follows a consistent accounting logic. (Lutter et al., 2016).

There are two simplifications in the industry-wide EE IO; 1) if an output from one factory should increase by 10% all the other inputs must increase by 10% as well 2) all factories producing products or offering services are compiled into 500 sectors, which means that also their economic outputs are aggregated. Because of these simplifications, it is possible to create an input-output table of the economy. (Hendrickson et al., 2006).

There is still no perfect method for the calculation of environmental effects, and also the EE IO method has its problems. EE IO is an LCA based method, but it has conquered the basic flaws of the process LCA method. The three most obvious problems are the aggregation error (Bullard and Sebald, 1988; Hendrickson et al., 2006; Ottelin, 2016), the assumption of price linearity (Ottelin, 2016) and the homogeneity assumption (Kitzes, 2013; Lutter et al., 2016; Wiedmann, 2009; Wiedmann and Minx, 2008). In the aggregation error, the economic sectors are divided and the emissions from a sector are allocated equally to the intermediate outputs and the final outputs (Ottelin, 2016). An example of this could be that the EE IO model is not separating plywood from CLT if they are produced in the same economic sector. The aggregation error is illustrated and described further in Figure 6. The assumption of price linearity is that the more a material or a product costs, the more it has emissions as well (Ottelin, 2016). This naturally is not always the case. For example, some environmentally friendlier materials, such as certified wood, can be more expensive than non-certified wood.

In EE IO, it is assumed that the product output is homogenous. This means that from one industry's products, no matter how different they are, they are mixed and calculated as an average and this deforms the results. (Lutter et al., 2016). The EE IO method is applicable for larger quantities such as companies, countries or product groups but it has only limited gains in looking at one product only because it assumes price homogeneity and homogeneity of outputs and their CO_2 emissions (Wiedmann, 2009; Wiedmann and Minx, 2008).

Many assumptions are made when an IO table is created and different decisions inflict the outcome (Inomata et al., 2006). All the assumptions and decisions increase the amount of uncertainty to the system (Owen, 2017). EE IO assumes that the technology used for production is the same with the imported goods and the ones made in the country they are used and in many cases this is not the reality (Suh and Huppes, 2005). Another source of error is that if an input is coming to the system free of charge, it is not counted into the environmental emissions (Kitzes, 2013).

The truncation error and the aggregation error are both inevitable outcomes of the different methods. Figure 6 illustrates the differences between the aggregation error of EE IO and the truncation error of process LCA (Ottelin, 2016).

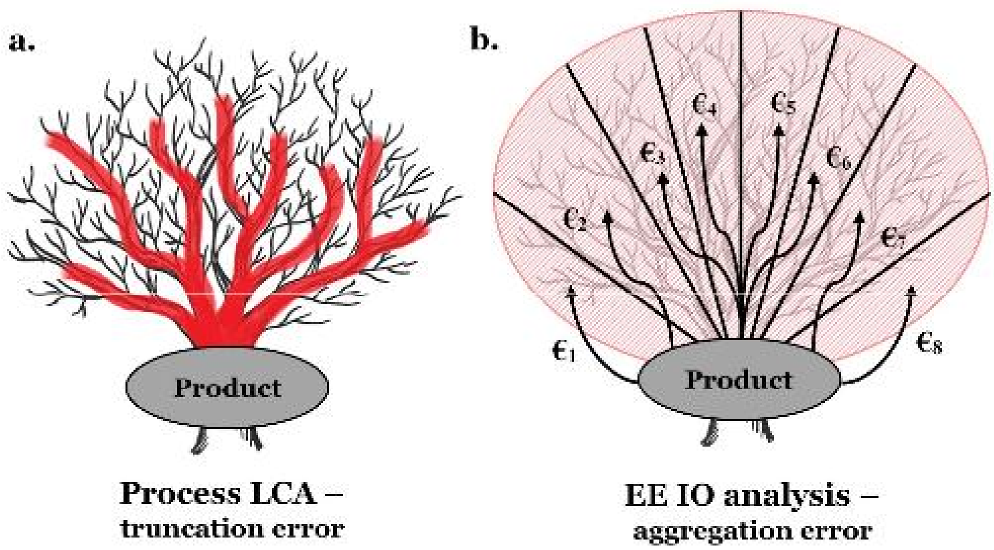

Figure 6. The truncation error and the aggregation error and their differences. a) Truncation error: the bottom-up process LCA focuses only on the main processes and their environmental impacts. Because of the system boundary selection in this, the black thin branches and their impacts are excluded from the calculation. b) Aggregation error: the

top-down EE IO analysis as a method is extensive and includes all the upper-tier processes that cause environmental impacts. The downside is that the inspection level is aggregated. (Ottelin, 2016).

The main advantage of the EE IO method is that it does not have the truncation error (Lutter et al., 2016). EE IO is more comprehensive than the process LCA approach because no arbitrary analysis boundaries have to be drawn (Hendrickson et al., 2006). Also, it is possible to include many aspects, such as employee costs, with only little effort to conclude the full analysis. With the input-output model, the responsibility of consumers and producers can be shared and there is no need to choose only one of them (Lenzen et al., 2007). The main advantage of EE IO in material footprint calculations is that it can be used for even very complex product chains and for whole industries. This is possible because the economic system is the base of the calculations. (Bruckner et al., 2012; Chen and Chen, 2013).

3.4 Method

3.4.1 Scope and system boundary

In this study, the scope was the case biorefinery and its production in year 2018. The study was a Well-to-Wheel study that included all upstream flows in the production chain and the use of the product. With fossil diesel, the emissions were calculated based on the values from Motiva (2010) and LIPASTO (2017), and the emissions of the use-phase compose around 88% of the total carbon footprint. Masses were used instead of area in the footprint and handprint calculations due to the available data and to avoid errors in the calculations.

The product-by-product IO table was used instead of the whole industry sector, and it was assumed that the end products, renewable naphtha and diesel, are the same product and all that the manufacturing facility produces. This corrects part of the homogeneity assumption when there is a sector for every single product (Kitzes, 2013), which was in this case one sector producing naphtha and diesel.

The carbon footprint was chosen as a part of the environmental footprint because GHG emissions have exceeded the planetary boundary (Rockström et al., 2009). Also, the effects of GHG emissions are significant and many policies are concentrating on them and thus companies have an interest in figuring out the carbon footprints of their products and in diminishing them. The GHG emissions could also be defined as one of the key material areas of the case company. The material footprint was chosen as the other way to measure the environmental footprint because it is in line with the Zero Waste concept. Another reason for choosing the material footprint were the planetary boundaries from which currently the biodiversity loss and nitrogen and phosphorus cycles are primary concerns. Material use was one of the key material areas and should be assessed regarding the net positivity.

The GHG Protocol Corporate Standard (2011) uses different classifications for different GHG emissions. The emissions are categorized in three different categories. Scope 1 includes all the direct GHG emissions. Scope 1 emissions are from sources that are owned or controlled by the company under examination. From the scope 1 emissions the direct CO_2 emissions of biomass combustion and GHG emissions that are not covered by the

Kyoto Protocol are excluded. Scope 2 includes the indirect GHG emissions from the electricity that is bought and consumed by the company under examination. Scope 3 includes all other GHG emissions. These are all upstream and downstream emissions and for example emissions from employee commute etc. (Ranganathan et al., 2015; Wiedmann, 2009). In order to calculate a full carbon footprint, all emissions from scopes 1, 2 and 3 must be included (Minx et al., 2009). In this study, even though the footprints were calculated as light versions, all emissions from all scopes were included.

Double counting is hard to avoid in any footprint calculations. If the producer calculates the footprint of its product when materials or products of other producers are used, then double counting easily occurs. Also, it must be known whether the calculations are done from the producer's perspective or consumer's perspective. (Lenzen et al., 2007). In this study, the consumer's perspective was used as was stated before. To avoid double counting, it should be monitored that there are no scope 2 or 3 emissions that could be or are reported as scope 1 emissions of another company or process (Behm et al., 2016). Organizations have power to affect their scope 1 and 2 emissions but also the scope 3 emissions at some level (Minx et al., 2009). In this study, the scope 1 emissions were the direct emissions from the production of the product. Scope 2 emissions were from production of electricity. These were calculated in EE IO with the monetary values. All the rest of the emissions from the EE IO analysis and the direct emissions from the use of the product, i.e., the emissions of burning the renewable diesel belonged to scope 3.

Tackling the calculation in a proper manner and according to the standards used in the life cycle assessment, the first important part was to set the system boundary for the calculations. The system boundaries of this study are illustrated in Figure 7. The EE IO model allows all the upper tier emissions to be taken into consideration. This means that not only the actual inputs such as water, electricity and chemicals, were included but also all emissions that were emitted during their making from the cradle to the time the new owner has the product. The coverage is illustrated in Figure 6 in Section 3.3.2. In the EE IO model the transportation is also accounted for with monetary values. For different transport methods all the emissions from the procurement of the materials for manufacturing the vehicle to the actual emission of using the vehicle were included.

From the production of the renewable diesel the EE IO method covered the construction of the factory and all the actions of the working people. These actions were for example education, dining and healthcare of the staff and the maintenance of the factory. The direct emissions of the production were added as a separate emission making the model a hybrid model. The emissions of management of waste water and waste were included in the system with the EE IO model. From the production some side streams are created. These were included inside the system boundary even though they are sold for other industries to be used as inputs. The last thing inside the system boundary is the use of the product and the emissions from the use. This made the study a Well-to-Wheel study, which is from the beginning to the end-of-life i.e. the use of the product. The Well-to-Wheel term is often used in relation to life cycle assessments of fuels.

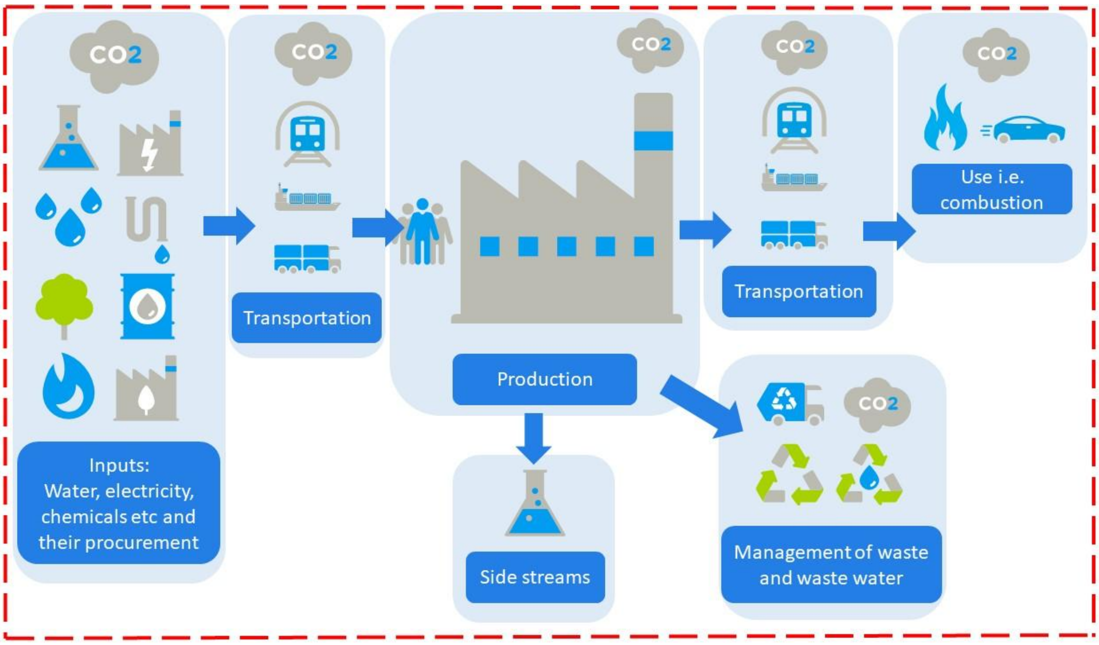

Figure 7. An illustration of the system boundaries of this study.

The BAU in this study was a 100% fossil-based diesel. The fact that this situation covers only the vehicles using diesel is not unambiguous. The vehicles using gasoline or natural gas could also be included in the baseline situation. In a similar case study of Grönman et al. (2019), the baseline was considered to be the current Finnish situation, where 88% of the used diesel is fossil-based and 12% is renewable diesel. This baseline was not though chosen for this study due to the incoherence of the replacement of the fossil diesel. If the case product is thought to be replacing this situation, some of the case product would merely replace itself, while it is calculated to be part of the 12% of renewable diesel used in Finland. Calculated in this study according to hybrid LCA-based values by Motiva (2010) and Seppälä et al. (2009), the Well-to-Wheel carbon footprint i.e. the BAU products CF was 85.4 g CO_2eqv/MJ. The fact that the CF of the BAU product was calculated with values based on a hybrid model, makes the values well suited for comparison.

The functional unit that was used for the carbon footprint and handprint calculations is 1 MJ and for the material footprint and handprint 1 kg. This means that all the emissions in the carbon footprint are calculated per 1 MJ gained with using the renewable diesel and for the material footprint and handprint the amount of material used per 1 kg of the product. The outcome could be for example x g CO_2eqv/MJ or x kg NR/kg. The functional unit for the carbon calculations was chosen due to the fact that masses and volumes could be misleading as different motors have different performances and the densities and energy contents of fuels can vary (Pexa et al., 2015). Also, this decision was supported by the fact that the case company had given the direct emissions in the unit of x g CO_2eqv/MJ. The functional unit of the material calculations is common in the MF literature and therefore also a good fit for this study regarding the comparability. By choosing to use these units, extra calculations and thus also occurrence of errors were avoided.

3.4.2 Calculating carbon and material footprint

In this study, the EE IO method was chosen due to the lightness of the calculation and the fact that it at least is not undermining the environmental emissions of the process. The CF and MF were calculated in a similar manner in this study. They cannot be calculated as one value and they were kept separate in the calculations. First the EE IO analysis was done from the monetary values of the case company.

Equation (2) in Section 3.3.2 was used in the calculations of both CF and MF. The ***M*** in the equation came from the environmental coefficients from Seppälä et al. (2009), and the ***f*** was from the monetary data of the case company (UPM, 2019a).

The CF and MF were based on the coefficients of environmental impacts per used euros. The coefficients were first converted into the right form of the 2017 value of the euro. The environmental coefficients are calculated in Seppälä et al. (2009) with a producer price-based method, which means that the coefficients are not including the sales margin or the gross margin of the sales. The monetary inputs given by the case company though included these margins and therefore these must be distracted from the given values. The margins of different industries were subtracted from the given monetary values according to the percentages from Tilastokeskus (2017).

For the GHG emissions in Seppälä et al. (2009), there is a coefficient describing the amount of GHG kg/€. For the material use in the same report, there is a coefficient describing the TMR (the used amount of material) in kg/€. This way by using the monetary values from the case company, it was possible to calculate the emissions and the material use for the different inputs of the process, transportation, waste management and the social actions in the process. The emissions of constructing the biorefinery were also included in the EE IO model. The full investment of the building was divided by the assumed operation time of 20 years and the coefficient was then used for the calculations. All these values were added up forming the carbon footprint (Behm et al., 2016) and the material footprint. The result was the total amount of material use or GHG emissions from the studied year 2018. Then using the annual production rates, given by the case company, the GHG emissions were generalized per one produced MJ and the material use per one produced kg.

The sums from the EE IO calculations were not fully covering all actions inside the system boundary. Therefore, to calculate the full footprint, the direct emission from the production and from the use were needed. These values were asked from the case company and added to EE IO values in g CO_2e/MJ. In this study, it was assumed that the GHG emissions and the CO_2e includes all the same gases with the same weights and therefore they were used in the calculations as equals. This way, the complete footprints were calculated in the form of x g CO_2e MJ for the CF and x kg NR/kg for the MF for the 2018 production.

The hybrid method implies that the data from the EE IO model is combined with data of direct emissions. The model for calculating carbon footprint with this hybrid method is illustrated in Figure 8 and material footprint in Figure 9. A serious advantage in the hybrid model is that it has a very large coverage on the indirect effects and supply chains and therefore there is comprehensiveness and accuracy at the same time (Lutter et al., 2016).

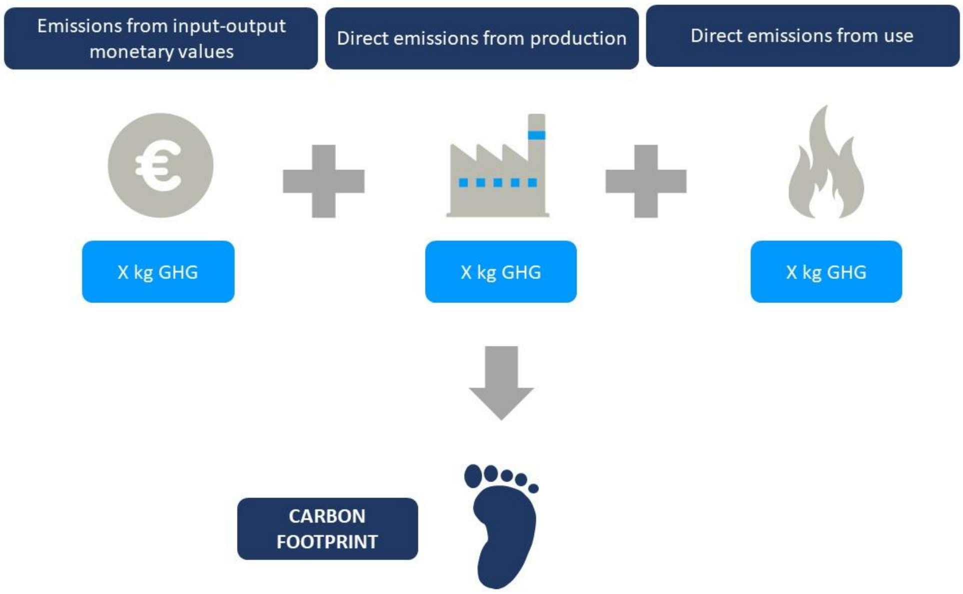

Figure 8. The formation of the carbon footprint with the hybrid life cycle assessment.

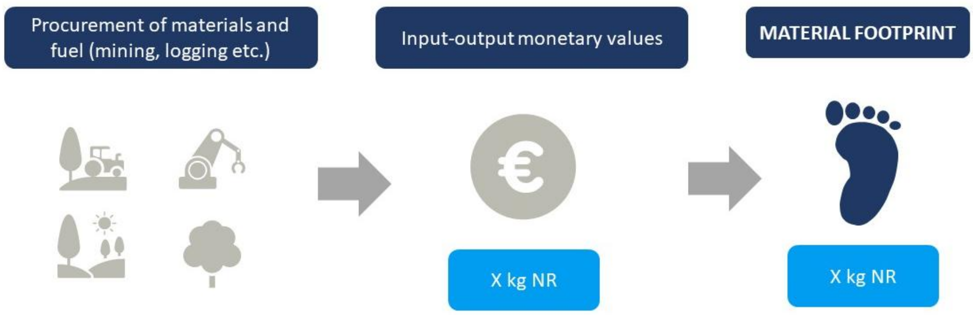

Figure 9. The formation of the material footprint with the hybrid life cycle assessment. NR = natural resources.

There are fundamental assumptions that were made when deciding what emissions and material uses were going to be included in the calculations. All the emissions and materials are inside the system boundary but due to the nature of the used materials and their end uses some exceptions were made. The first assumption was that the emissions and material use of the processing residue CTO used as an input, were assumed to be zero. According to the Finnish law of biofuels and bioliquids (393/2013) no GHG emissions are emitted from the life cycle of waste or remains before their collection (FINLEX, 2017). All the emissions of this secondary input were therefore zero. In this study, this method was used since the same system was used by the case company, and this way the calculations of this study and the ones made by the case company were compatible.

The second major assumption was that the direct emissions of the use-phase were counted as zero. This assumption was based on the directive of the European Commission (2015) where it is stated that the use of biofuels and bioliquids should be counted as emission free. Since the biofuel is merely emitting the same amount of CO_2 as it has already sequestered from the atmosphere while growing as a plant, the emissions were considered to be zero. The same presumption was used by the case company and therefore this assumption also enhances the compatibility of the calculations.

The third assumption was that the emissions and material use of the residues of the case product fabrication were assumed to be zero, following again the Finnish law of biofuels and bioliquids (393/2013) (FINLEX, 2017). In this case, the residues were counted as remains and they are sold to other industries and used as an ingredient of perfume production and energy in pulp industry. Furthermore, this assumption was used by the case company in their calculations.

In addition to these assumptions, different aspects were affecting the size of the footprints. For example, there is only one environmental coefficient value mentioned in Seppälä et al. (2009) for the natural gas and it is not specified from where the natural gas is imported to Finland. At the moment, the natural gas forms the largest amount of both GHG emissions and the material use, and therefore it was relevant to discuss this matter. The distribution of the emissions and material use in this case is presented in more detail in the Section 4.

Another value affecting the results was the assumed life of the biorefinery. The case company was assuming that the life is 20 years, which is a conventional estimate for a refinery. If the life would have been for example 25 years it would have affected more on the material footprint than the carbon footprint, but still it would have had an effect.

The share of the naphtha going to bioplastic production and as a biocomponent of gasoline is not stable, but it is known that a smaller share is going to the bioplastic production. Even though the naphtha is used for production of renewable gasoline, in this study it was compared to the BAU fossil diesel values. The GHG emission values of fossil diesel and fossil gasoline are fairly similar (Motiva, 2010; Seppälä et al., 2009) and for simplicity the CF value was compared to the values of fossil diesel. According to the suggestion by the case company all the naphtha was calculated to be a component of renewable diesel production. This affected the calculations as it increased the total amount of the renewable diesel.

3.4.3 Calculating carbon and material handprint

The handprint in this study was calculated according to the instructions by Norris (2015) and the guidelines in Grönman et al. (2019) that follow the LCA structure. Only the direct handprint could be calculated in this case while the indirect handprint is forming from imprecise positive impacts that could not be calculated with the same accuracy as the direct handprint. The direct handprint was calculated separately for materials and carbon. As an example, the carbon handprint can consist of the avoided carbon emissions due to the better process (direct handprint) and the possible action of the case company in regard of carbon sequestration (indirect handprint). All the wood used in the case company is certified with PEFC or FSC Chain of Custody (UPM, 2019d) and thus it can be assumed that at least the same amount of new trees are planted as is cut. An illustration of the theoretical formation of the handprint is shown in Figure 10. The functional unit and the system boundary for the handprints were the same as for the footprints to make them comparable. In this study, the handprint was compared to the purely environmental footprint and therefore only the environmental aspects were considered.

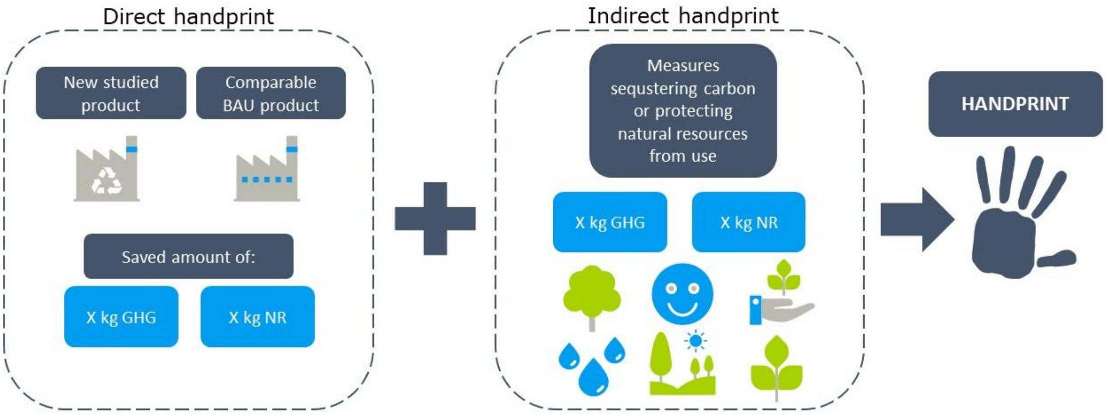

Figure 10. The formation of the handprints in this study. NR = natural resources

As was stated in Section 3.4.2, the emissions of the use of the product, CTO production and the side streams were already taken out of the footprint and therefore they were not included in the handprint either. Another possibility would have been to include these emissions to the footprint and then calculate the positive impacts to the handprint. This is though only double the work as comes clear from the example of the emissions of the use. The positive impact of the use was that the amount of carbon emitted in the use of the product is the same amount that was sequestered while the tree was growing. This would mean that all in all the positive and negative impacts cancel out each other and the result is zero. Therefore, it was easier to merely remove the emissions from the footprint.

The direct handprint was calculated from the emissions and material use that was avoided by using the renewable diesel instead of diesel made from fossil fuels. The BAU product used for the comparison, completed all the four requirements of Grönman et al. (2019). The fossil diesel was closest to the actual product and would be replaced when more renewable diesel was used. The assumption was that the renewable diesel is replacing the use of fossil diesel and not merely increasing the total use of the diesel. Currently the renewable diesel is not distributed solely but is blended in the distribution network.

To be able to compare the case product to the BAU product and their emissions and material use, the values of the footprints were needed. The carbon footprint of the case product can be compared to the similar carbon footprint of diesel made from fossil fuels. The value in this study was calculated to be 85.4 g CO_2e/MJ based on Motiva (2010) and Seppälä et al. (2009). For the material footprint there was no similar comparable value readily available and therefore it was calculated in this study using the Wuppertal Institute's Material Intensities (MI). The intensities from five different input categories (abiotic and biotic materials, water, air and earth movement in agriculture and silviculture) are summed up to get the material footprint of the diesel made from fossil fuels (Wuppertal Institute, 2014). This Material Intensity Per unit of Service (MIPS) is a process LCA-based concept where the shortages, such as the lack of unused materials in the calculations, of the LCA method are covered by using the Ecoinvent database. The MI values include all upstream processes and the concept is therefore a cradle-to-gate method (Wuppertal Institute, 2014). Therefore, the values of the MI were comparable to the values of this hybrid model.

The use of air as the fuel is burning, was separated from these intensities because it is not usually included to the calculations. As a comparison, the material footprint of the fossil diesel was without the air use 11.08 kg NR/kg of diesel and with the air use it was 14.28

kg NR/kg of diesel. These values were compared to the material footprint of the renewable diesel to see how the air use would affect the footprint values. This comparison will be discussed further in the Section 4.

The indirect handprint is constructed from all the positive impacts of the company that would not have happened without their contribution and that are not required by law (Behm et al., 2016; Norris, 2015). This includes all the positive impacts that happen outside of the main production process. An example of possible indirect carbon handprint could be carbon sequestration by increasing carbon sinks with afforestation. In this study, when the system boundary was set to include only the one production factory, the indirect handprint would be formed from the actions of the corporation and then divided to the share that the case company has from the corporation. The share could be measured for example by employees working in different sections of the corporation.

3.4.4 Calculating Net positivity

The net impacts were calculated by subtracting the handprint value from the footprint value (Norris, 2015). They were in the same units and therefore as an outcome there was one value for the material use and one for the GHG emissions. If the outcome is below zero, then the action is net positive and if the outcome is above zero, then the action is net negative. To avoid the misunderstandings regarding the positive and negative effects, the terms “below zero” and “above zero” are used for the value of this calculation.

In Section 2.3, it was stated that the “standard perspective” is used. This means that it is taken as given that the company already exists, and the handprint therefore is formed from the avoided emissions i.e. direct handprint (Norris, 2015). The other option would be to only calculate the indirect handprint and achieve net positivity through actual positive net impacts (Norris, 2015). In the “standard perspective” there are still more physical emissions than there is sequestration of emissions even though a company or process would be net positive. More discussion of this topic and its legitimacy is in Section 4.4.

In the case of the “contingent existence perspective” these different net positivity values would mean the following. If the value is below zero, it describes the amount of GHG emissions that are sequestered or natural resources that are secured from use “over the needs”. If the value would be zero, that would mean that the exact same amount of emissions is sequestered, or materials are secured, than are emitted or used. This means that “over the needs” is more than is needed to cover the emissions or use. If the resulting value is above zero, it describes the amount of emissions or material still needed to sequester or secure to achieve the zero i.e. how much larger the handprint should be for it to be larger than the footprint.

In this study the “standard method” was used and the description of the “contingent existence perspective” is not fully accurate. The largest part of the handprint was formed with the direct handprint, which is only accounted for in the “standard method”. Regarding the “contingent existence perspective” the case product would not be net positive. If the direct handprint alone is larger than the footprint, it merely means that using this new product would be a better option than using the comparable BAU product. The value from the net impact calculation being below zero, indicates the amount that the new product is better than the BAU product. The smaller the value, the better the product is. If the value would be above zero it would mean that the new product is not a better option than the BAU product.

4. Results and discussion

4.1 *The results and comparison to relevant values*

4.1.1 Carbon footprint

The result of the CF calculation with the hybrid model is illustrated in Figure 11 in which the components of the calculation are distinguished.

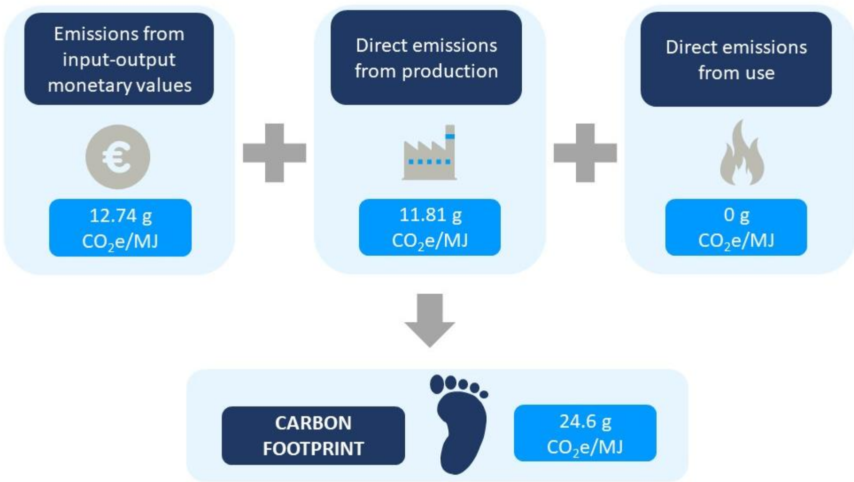

Figure 11. The illustration of the CF results calculated with the hybrid model.

In this study, the CF value was formed from three parts illustrated in Figure 11. The first part (12.74 g CO_2e/MJ) was calculated with the EE IO model using the environmental coefficients by Seppälä et al. (2009) and the monetary input data from the case company (UPM, 2019a). The second part was calculated from the direct emissions by the case company (UPM, 2019a) to be 11.81 g CO_2e/MJ. The third part was the emissions from the use that were calculated to be 0 g CO_2e/MJ according to the Finnish law of biofuels and bioliquids (393/2013) (FINLEX, 2017).

The carbon footprint calculations compared to the calculations of the case company and the BAU product are presented in Table 4. The computation was done based on the description in Section 3.4.2. The CF is the only value that can be compared to both, the calculations of the case company and the comparable fossil BAU product. Table 4 shows all these values in the same unit g CO_2e/MJ. The case company has calculated the value to be the smallest. It is still not deviating from the value of this study greatly. Both CF values for the case product were significantly smaller than the CF value of the BAU product, which was a positive outcome and answered the first research question regarding the comparison of the carbon footprints calculated with the process LCA and with the hybrid model. The CF value of the BAU product includes the emissions from the use of the fuel. As was mentioned in Section 3.4.1, the emissions of the use of the fuel i.e. burning, forms around 88% of the whole CF and in this study the emissions of the use were not included in the CF. The CF of the BAU product without the burning emissions was only 10.6 g CO_2e/MJ (Motiva, 2010; Seppälä et al., 2009). This is lower than the production of the case product due to the polished process of producing fossil diesel for quite some time. In this sense the main difference of using the renewable diesel was in the use-phase and the exclusion of it from the calculation.

Table 4. The carbon footprint results of the case product from this study, the case company and the comparable fossil BAU product.

The carbon footprint	**Calculation method**	*g CO_2e/MJ*
Case product, calculated in this study	Hybrid LCA	24.55
Case product, calculated by case company	Process LCA	15.30
BAU product, calculated in this study	Hybrid LCA	85.40

There are many different reasons for the CF from this study to be greater than the one calculated by the case company. Table 5 lists the different aspects that are affecting the larger value of the CF with the hybrid model compared to the process LCA model. The case company has used the traditional process LCA for the calculation and the construction of the production factory was not included in their calculations. This would have increased their CF value if it would have been included. This study used the monetary values from only the year 2018 and the production rates were also from the same year. The case company has used third party certified values that were generated from a longer period of time. In the monetary inputs, a great turnaround of 2018 was increasing the amount used for construction services greatly. Another factor that affected the CF value of this study was that with the EE IO model, it was possible to include all social, health care and other services into the calculation. These services could not be included in the CF value of the case company. The effect was though only 1% of the whole value.

Even though the construction of the whole manufacturing facility was included in the hybrid model calculations and not in the traditional process LCA, it only formed 5% of the whole carbon footprint (Table 5). The major turnaround of the manufacturing process in 2018 increased the expenses of construction services with 70%. The CF was though only 3.8% larger due to this. The turnaround also reflected to the production rates and therefore it is still viable to keep the 2018 specific values in this study.

Table 5. The aspects affecting the larger CF calculated with the hybrid model compared to the process LCA and how much is the effect in percentages.

Aspects increasing the CF value calculated with hybrid model	Percentage of increasement (%)
The GHG emissions of constructing the manufacturing facility are included	5
The turnaround of the year 2018 is decreasing the production rate and increasing the used monetary inputs	4
The EE IO model is enabling the inclusion of all emissions from the services related to the operations in the manufacturing facility	1
All the upper tier emissions are included with more comprehension than can be achieved with process LCA	not calculable

The different impact factors used in the calculation of the CF are based on the environmental coefficients of Seppälä et al. (2009). The distribution of the affecting factors from the largest to the smallest is presented in Figure 12. The greatest effect to the CF was from the use of natural gas in the production process. The meaning of the natural gas to the whole CF is discussed further in Section 4.3. The second largest part was the production and distribution services of electricity and the third largest was the chemicals used in the process. Together these three largest parts formed 78% of the whole CF.

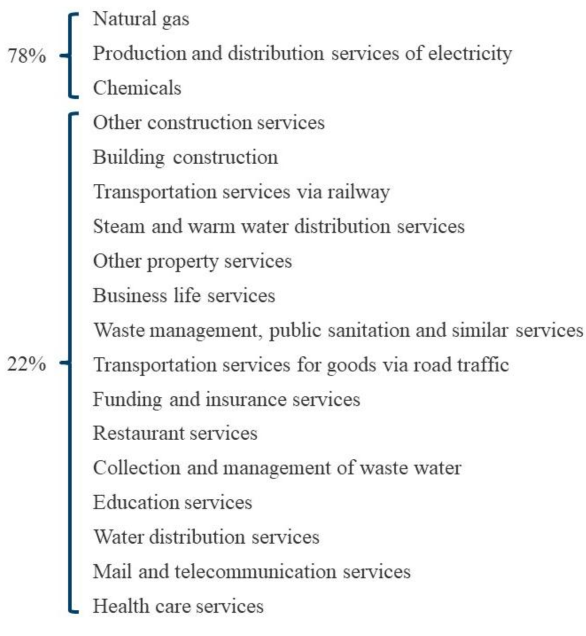

Figure 12. The distribution of the factors affecting the CF from the largest to the smallest.

4.1.2 Material footprint

The material footprint could be compared only to the BAU product. The MF of the BAU product was especially calculated in this study for comparison to the case product according to the MI-values (Wuppertal Institute, 2014). MF of the case product was calculated in a similar manner as CF using the environmental coefficients by Seppälä et al. (2009) and the monetary input data by UPM (2019e). The result of the MF calculation and how it is formed with the hybrid model is illustrated in Figure 13. Table 6 presents the MF values in the same unit of kg NR/kg.

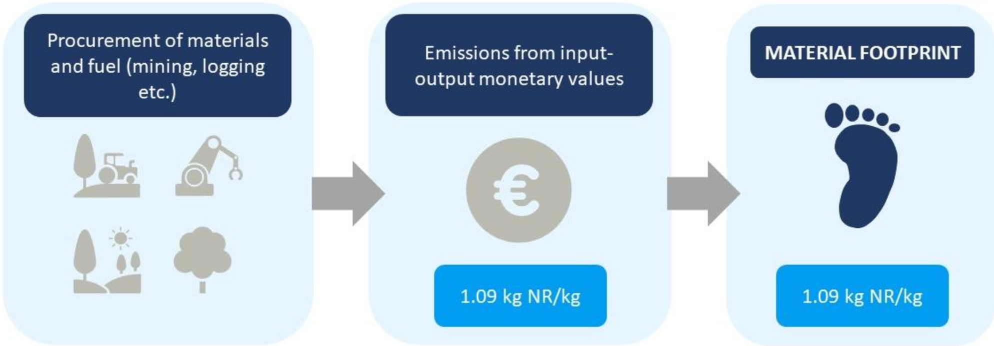

Figure 13. The illustration and formation of the MF results calculated with the hybrid model. NR = natural resources.

Table 6. The material footprint results of the case product from this study and the comparable fossil BAU product. NR = natural resources.

The material footprint	**Calculation method**	*kg NR/kg*
Case product, calculated in this study	Hybrid LCA	1.09
BAU product, calculated in this study with MI-values from Wuppertal Institute (2014)	Process LCA	11.08

The MF of the BAU product was naturally much greater than the one for the case product due to the mining of the fossil ingredients from the soil and thus moving massive amounts of soil in the process. If the use of air in the burning of the fuel would have been included into MF of the case product, it would have increased by 75% and been 4.29 kg NR/kg. From the MF perspective, the case product was significantly better than the BAU product.

The distribution of the affecting factors to MF from the largest to the smallest is presented in Figure 14. The greatest part of the MF was formed from the use of natural gas. The production of natural gas is also using great amounts natural resources due to the moving of the soil to get access to the gas. The second largest part was the building of the manufacturing facility and the third largest part was the chemicals used to produce the product. Together these three largest parts formed 75% of the whole MF. The construction of the manufacturing facility formed 27% of the whole MF and thus, if a MF would have been calculated with the process LCA, it would have been clearly smaller.

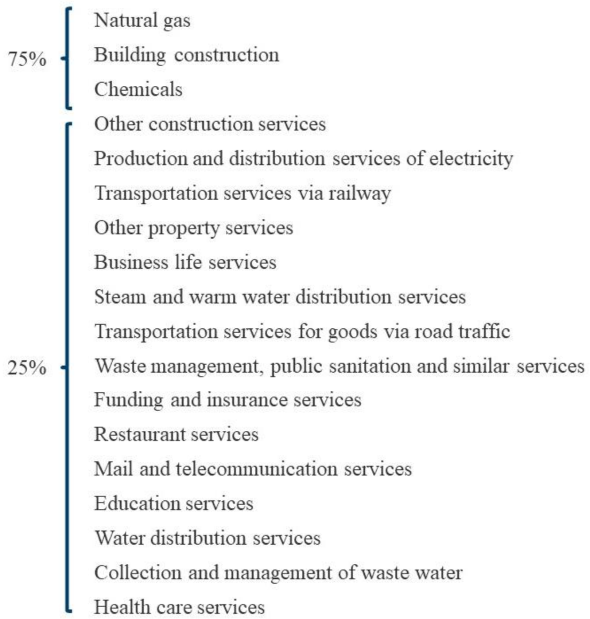

Figure 14. The distribution of the factors affecting the MF from the largest to the smallest.

4.1.3 Carbon and material handprint

The result of the carbon handprint calculation is illustrated in Figure 15 and the result of the material handprint in Figure 16. It is hard to compare the results from the handprint to any other results as the handprint values are always case specific and the BAU product, to which the product is compared, can variate greatly and therefore cannot be compared to other handprints.

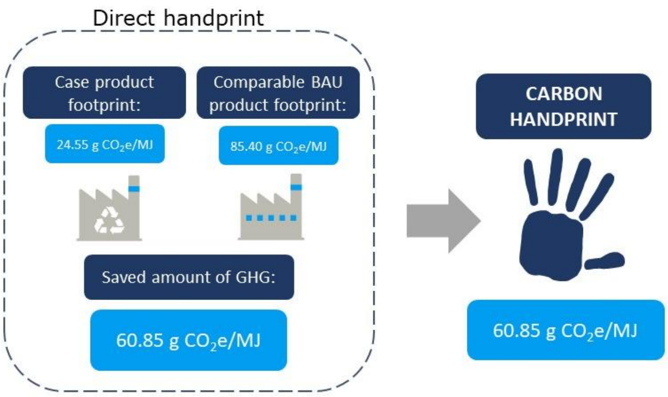

Figure 15. The illustration of the carbon handprint result.

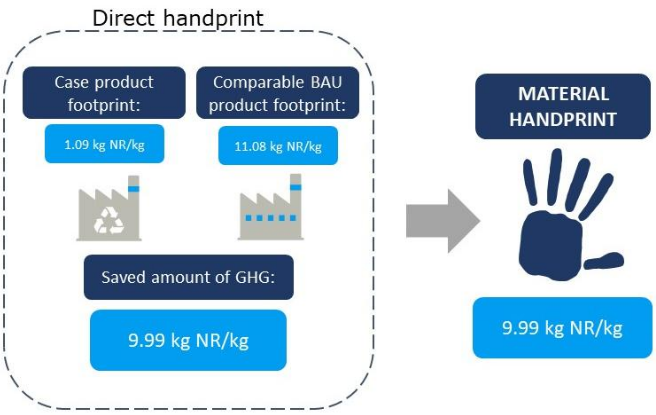

Figure 16. The illustration of the material handprint result.

The results of the handprint calculations are presented in Table 7. The carbon handprint result indicates that 60.85 g of GHG per each MJ was saved compared to the baseline situation of the fossil diesel. The material handprint result indicates that 9.99 kg of natural resources was saved per each kilogram compared to the use of fossil diesel. The indirect handprint in this case was zero and does not add anything to the total handprint.

Table 7. The handprint results of the case product calculated in this study.

Handprint	Value
Carbon handprint, calculated in this study	60.85 g CO_2e/MJ
Material handprint, calculated in this study	9.99 kg NR/kg

4.1.4 Net positivity

The results of net positivity and their formation are presented and illustrated in Figure 17. When the footprints and the handprints had been calculated, the net impacts were calculated by subtracting the handprint values from the footprint values. With this method the net impacts regarding the GHG emissions were -36.3 g CO_2e/MJ. The value was below zero and therefore implies that the product is net positive regarding the GHG emissions. This means that for the climate it is better to use the product of the case company and by using the case product 36.3 g of GHGs are saved per each MJ compared to using the fossil diesel. For the material net impacts the value was -8.9 kg NR/kg. This means that also the net impact regarding the material use is net positive while the value was below zero. For every used kg of the case product 8.9 kg of natural resources are saved compared to using the fossil diesel.

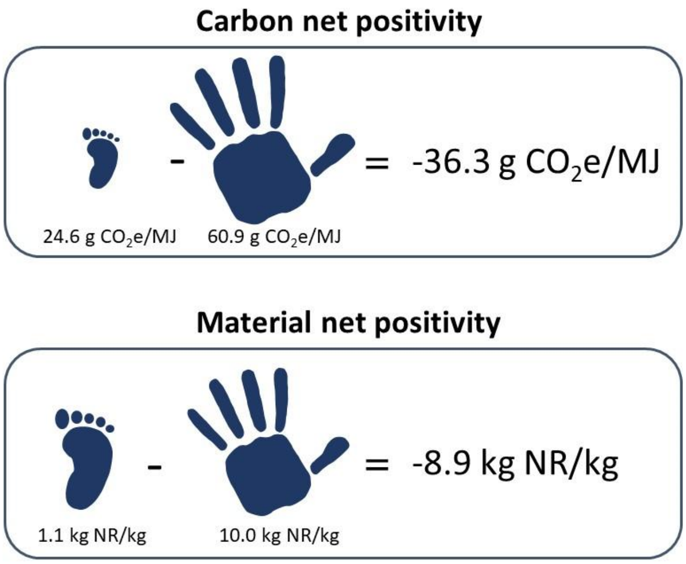

Figure 17. The results of carbon and material net positivity illustrated. NR = natural resources.

4.2 General discussion

The results of this study provided a simplified quantification of the case product and the environmental impacts of it compared to the fossil diesel. The EE IO method has been used for many different studies providing similar footprint results than with the traditional process LCA (Hendrickson et al., 2006). The EE IO method has been used for example for analyzing environmental impacts of water distribution systems (Herstein et al., 2011), carbon footprint of food (Virtanen et al., 2011), alternative automobile fuels (MacLean et al., 2000) and environmental implications of electric cars (Lave et al., 1995) just to name a few. Hendrickson et al. (2006) presented additional implications. There were no fully comparable studies made concentrating on the renewable forestry based biofuels made from side streams, but MacLean et al. (2000) stated that biofuels could potentially be the solution to achieve required emission reductions to satisfy the Kyoto Agreement. Therefore, the fact that the case product is made from wood-based processing residues is a valuable aspect but cannot be compared strictly to MacLean et al. (2000) or any other results.

The results from the handprint calculations could not be compared in a similar way as the results of the footprint calculations could be to any other research due to their case specific nature. The handprints in this study were calculated for the year 2018 according to the production rates of the year (UPM, 2019a). In Grönman et al. (2019), for example the carbon handprint was calculated for a specific travel distance. Therefore, these handprints were not comparable. In Grönman et al. (2019) only the direct handprint was taken into account and there was no mention of the indirect handprint. Also, the calculations were only concerning GHG emissions. Otherwise the method for calculating the direct handprint was in line with the article and following the structure of LCA.

There are different ways to exemplify the positive effects of the case product. The savings in GHG emissions if the 2018 production of the case product would replace fossil diesel were 243,523 tons of GHG. This amount of GHG emissions are emitted if a gasoline or diesel car is driven 40,000 times around the world with 1.7 passengers (LIPASTO, 2017) or flying from Helsinki to Bangkok and back around 172,000 times (Atmosfair, 2019; Finnair, 2019). The amount of GHG would also cover 74% of the Finnish forestry industry's annual GHG emissions or 6% of Finnish road traffic's annual GHG emissions (Tilastokeskus, 2018). These examples illustrate well the magnitude of this kind of change.

With the net positive results, the situation was similar to the handprint results, they were not directly comparable to any other cases. The method for calculating though was following the instructions of Aeron-Thomas and Le Grand (2015) and Norris (2015). The "standard perspective" was used for the calculation of the net positivity. This means that in reality there are still more negative impacts than positive even though they are "net positive". To clarify this with an example, even if all the vehicles in Finland would use this case renewable diesel and no fossil diesel were used, there would be GHG emission to the atmosphere. With the "contingent existence perspective" if the operation would be net positive or even net neutral, the situation would be that there is the same amount of GHG emissions to the atmosphere than there is carbon sequestration or there is even more sequestration than there are emitted emissions. This is very important to take into account when communicating to the larger audience in order to avoid green washing and giving false information to people.

An interesting question was how well the handprint assessment fits together with footprint assessment and could these two be used together to assess the net impacts. Both the footprint and the handprint assessment were done in this study according the accepted structure of an LCA (ISO 14040, 2006; ISO 14041, 1998; ISO 14044, 2006). Although the description of an LCA is broad and the assessment can be done with various methods including for example the process LCA and the EE IO model, going in accordance to the standards made the calculation of the footprint and the handprint equivalent. Therefore, the calculation of net positivity based on the handprint and the footprint should be acceptable as well.

4.3 Suggestions for improvement in renewable fuel production

There are several different ways to decrease the footprint and increase the handprint of the case product. In both MF and CF, the biggest impacts were coming from the use of natural gas and the use of the chemicals. In addition to these two impact categories, the electricity production was affecting the result of CF and the construction of the manufacturing facility the results of the MF.

The share of the natural gas was the biggest factor in both footprints as was stated in Sections 4.1.1 and 4.1.2, but it needed to be discussed whether the share is actually as massive as it is according to the EE IO calculations. Because natural gas is not produced in Finland and is always imported here from Russia, the estimation of the emissions was harder. In the environmental coefficients the emissions of the natural gas were derived from international Ecoinvent database (Seppälä et al., 2009). This means that the coefficient might not be presenting the emissions of the Russian natural gas imported in Finland in the most accurate way and this affected the calculations. Despite of this inaccuracy, the magnitude of the emissions of using the natural gas was reasonable and reflected the share of the monetary inputs used to buy the natural gas. To decrease the effect of the natural gas, it would be advisable to substitute the use with some other form of energy. For example, the use of renewable biogas would substantially decrease the effects on both the CF and the MF because the amount of natural resources used and the GHG emissions from producing biogas from waste are substantially smaller.

The chemicals used in the process are mainly catalysts and the decreasing of the use of these chemicals would need a proper analysis of the whole process. The use of the production and distribution services of electricity had greater effect on CF than MF. To decrease the effect of the impact category, the amount of electricity should be decreased. This could be done either on the process level, on the employee level or both. In the process level it would mean that all the process parts using electricity should be reevaluated and redesigned to minimize the use of electricity. On the employee level, it would mean basic measures such as closing the lights when not needed, using the computers in an energy efficient way and other office related measures. A great share of MF was formed from the material use of constructing the manufacturing facility. This material use is hard to avoid after the construction is done.

There are many different ways to increase the handprint. The direct handprint naturally increases when the avoided emissions are increasing. This means that if the studied product is improved, the direct handprint also increases. To increase the indirect handprint the company needs to figure out ways to secure natural resources from use and to sequester carbon emissions. These could be achieved for example with protecting old forest, increasing the land area of forest or planting new trees to sequester CO_2 from the atmosphere to increase the carbon sinks.

4.4 Limitations

There can be different types of limitations, others are the down sides of the used methods and others concern the data. All these limitations, errors and made compromises are discussed in here.

The limitations of the used methods were mainly concerning the EE IO method. In the EE IO method and in the used environmental coefficients, the changes in inflation for indices were not taking the changes in improving technology into account. Only the monetary changes were accounted for. There was also an assumption that all the imported products are produced with the same technology and emissions as the ones made in Finland and for the imported products this was naturally not true. The economic and environmental data is reflecting past practices (Hendrickson et al., 2006) even though this might not be the reality. One limitation in this study was that all the positive effects that were not decreasing the GHG emissions or the use of natural resources could not be calculated into the handprints. To include these other positive impacts for example a social handprint should be assessed.

The limitations of the data were related to the fact that there were no precise change coefficients for the environmental coefficients for all the product types of the case inputs to perceive the inflation change of the coefficients. Therefore, more generic values from Tilastokeskus (2017) for the whole product group had to be used. In the material footprint, the comparison value of the fossil diesel was calculated based on the MIPS method that was not entirely similar to the one used for the renewable diesel. This might have affected the compatibility. Also, the assumption that the naphtha was compared to the fossil diesel values even though it is used as component of renewable gasoline, was affecting the results.

For the environmental coefficients the errors in the data used, were that all the coefficients were averages of the whole product group and the data was relatively old as it was from

2005. There might have also been survey errors in the collection of the original data for the input-output model of the environmental coefficients and missing data of different environmental effects and of specific sectors. Also, as the environmental coefficients existed only for certain sectors and product groups, the data was incomplete and as the products were grouped there was aggregation.

The results of the handprint were covering only the direct handprint. The calculation of the indirect handprint would have provided needed record of the effects of the indirect handprint to the total handprint, but due to the lack of direct action of the case company and publicly available information of the positive impacts, it could not be calculated. In Grönman et al. (2019) only the direct handprint was mentioned and therefore even without the indirect handprint this study was going along the guidelines of the article. The positive measures mentioned in the Section 3.4.4 could have also suited into a social handprint if it was in the scope of this study.

There were many different aspects that complicated the calculation of the indirect handprint based on the positive impacts mentioned in Section 3.2.1. It was difficult to calculate the saved emissions from the forestation operations in Uruguay since there was no publicly available information of the exact previous use of the land and the time when the forestation process begun. The sequestration of CO_2 in forests needs to be considered carefully (Behm et al., 2016) and the estimation was not in this case accurate enough to be compared to the direct handprint. To allocate all the benefits for the case company from the whole corporation would be questionable. Also, it was not publicly available information to what extent the protected areas in Finland were sold or given to the state by the state's request and not as the corporation's own initiative. The amounts of GHG the carbon sink forests in Uruguay and Finland sequester was not publicly available information and therefore could not be included in the indirect handprint. These positive impacts were mentioned but not calculated as the indirect handprint.

Due to the system boundaries of this study, only the carbon handprint and the material handprint were calculated. In this case, some major positive impacts would have been gained if for example the social aspects would have been calculated into the handprint. The case company collaborates with many local groups and also induces more positive action by developing oil crop cultivation on underutilized agricultural land that could be used for biofuels and animal feed production (UPM, 2019b). One large factor that could not be included in the material or carbon handprint was that the new renewable diesel does not need any new infrastructure or changes to the engines. This means that a lot of savings in the infrastructure is made but it was not quantifiable and therefore could not be calculated into the handprints. The savings in the infrastructure are affecting the feasibility of the whole production of biofuels (MacLean et al., 2000). Also, the fact that the integrate area where the biorefinery is, is self-sufficient regarding electricity, could increase the handprint but was not included in these calculations due to the wide assumptions needed.

The result of the net positivity calculation was providing a clarification of the situation. The renewable diesel was a better option compared to the diesel made from fossil fuels. Even though based on the used "standard perspective" the process would be net positive as the result was below zero, there are still GHG emissions to the atmosphere and material use. If the indirect handprint of the case company could be calculated, the "contingent existence perspective" could have been used and the results would indicate the actual net emissions and material use of the product.

The most obvious disadvantage in traditional process LCA is the intense work and time-consuming process to produce the results. With the hybrid model, the same analysis can be done with less effort and time. The results of this study show that the hybrid model yielded similar results compared to the process LCA. The resulting values were slightly larger when calculated with the hybrid model due to the wider system boundary that was used compared to the process LCA.

Rebound effects were excluded from the scope of this study. The rebound effect is creating an unintended effect on the measures to reduce environmental impacts (Greening et al., 2000; Nässén and Holmberg, 2009; Ottelin, 2016). The rebound effect usually has a negative impact but can also have a positive impact on the assumed environmental effects. The negative impact would occur due to the measures of reducing environmental impacts and the impacts would actually become larger. For example, if a product is made more environmentally friendly and becomes cheaper in the process, this leaves the consumer with more money and this money is potentially used for buying something that has negative environmental impacts, and, in the end, the net impact is more negative than with the original product. The positive outcome, which was the case in this study, is that the case product is more expensive than the BAU product and by buying the case product the consumer has less money to use on products that would have more negative environmental impacts. These unanticipated positive impacts can also be called spill-over effects or co-benefits (Hertwich, 2005)

4.5 Further research

There is still need for further research to generalize the optimal way of calculating the handprint. Also, more scientific research and case studies on the handprint calculations and net positivity is needed to find the scientifically sound way of calculating. More references on the footprint calculated with the EE IO method would help the comparison of results. The comparison of EE IO and process LCA method with cases would also serve as a good reference for this study.

Regarding the material footprint, there is a need for more case studies that would provide more information on material footprints of products for comparison purposes. Wuppertal Institute (2014) did not include MI-factors of biofuels or other products made from side streams. If this kind of MI-factors were available, it would be possible to assess the benefits of recycled products already in advance. However, the use of side streams is always case specific, and it can be hard to produce proper estimations.

In Tables 8, 9 and 10, the advantages and the disadvantages of the used methods are described. Table 8 describes these for the hybrid model, Table 9 for the handprint concept and Table 10 for the net positivity. These tables summarize the needs for further research and the limitations of the methods while highlighting also the benefits of the used methods.

Table 8. The advantages and disadvantages of the hybrid model.

Hybrid model	
Advantages	*Disadvantages*
Avoids truncation error	The values are aggregated
Light and easy	Improving technology is not accounted for
Data needed already exists in companies	Assumption that all imported products are produced with same technology as in the nation considered, which in Finland's case might underestimate the emissions
Calculating is quick compared to process LCA	Product groups might not be equivalent to the actual products
A wider system boundary is possible	
Does not leave out any important factors	

Table 9. The advantages and disadvantages of the handprint concept.

Handprint	
Advantages	*Disadvantages*
The positive aspects can be calculated	Innumerate positive aspects cannot be included
Follows the same LCA process than the footprint making them comparable	There is no scientifically approved method for the calculation
Provides new information for a company	There is still need for more research and case studies
Is an advantage for a company	

Table 10. The advantages and disadvantages of the net positivity.

Net positivity	
Advantages	*Disadvantages*
The net impacts of company or a product can be calculated	The concept is still new and there is not a scientific consensus on the calculation
Has positive ripple effects	Two very different definitions that could be misleading for the communication
Provides new information for a company	A goal that takes a long time to achieve

5. Conclusions

The lighter footprint calculations with the hybrid life cycle assessment model were done with the same system boundary that was used for the process LCA. The models included all the emissions from all the scopes, which made the study a Well-to-Wheel study. The hybrid life cycle assessment for the footprint calculations was faster and required less work than the process LCA.

The first research question was asking whether the hybrid life cycle assessment gives similar values with the process LCA. The comparison of CF to the case company's own calculation showed expected results. CF in this study was slightly larger due to the method that enables the including of more aspects to the calculations and on the other hand was using estimated emission and material use coefficients that were at least large enough to represent all the products in the product group. MF could only be compared to the BAU product and based on that comparison the value from this study looked at least to be in the right proportion being significantly smaller than MF of the fossil diesel, which was a positive outcome. The life cycle stage where the benefits were occurring was clearly the use phase and therefore it was important that also the use phase was included in the system boundary. The answer to the first question was that this hybrid life cycle assessment was a suitable method for calculating at least the carbon footprint and according to the similar method used for the material footprint, also the material footprint.

The answer to the second research question about the handprint of the case product was the amounts of GHG emissions and materials saved compared to the use of the BAU product. The handprint calculation provides a useful estimation for a company to compare their product to the baseline without taking any shortcuts in the system boundaries and the accuracy of the calculations. The method was following the structure of an LCA. Only the direct handprint could be calculated in this case study, while the indirect handprint was forming from imprecise positive impacts that could not be calculated with the same accuracy as the direct handprint.

The last research question was: "What are the net impacts based on the footprint and handprint assessment?". The net positivity assessment is a new method and there is no regulated way to calculate the net impacts. One way presented by Norris (2015) was to calculate the difference of the footprint and the handprint. According to that, this method would work while the calculation worked for CF and MF and thus also for the handprints. The net positivity assessment works as a useful tool for companies to gain knowledge on the environmental effects of their operations. This could be used as a guidance for improvements of the processes and products. The net positivity results were both for the GHG emissions and the material use below zero and therefore imply that the case product is net positive. This means that for the climate and the natural resources it is better to use the case company's product compared to the BAU product. Even though the results were below zero there are still net GHG emissions to the atmosphere and net material use.

These results could be used in the internal and external communication or for example in the sustainability reports of a company. It is though important to communicate the net positivity in a proper manner to avoid misleading communication. This way the net positivity concept keeps providing positive outcomes in the future.

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Appendix 1. Zero waste hierarchy

Rethink	Design and purchase products from reused, recycled or sustainably-harvested renewable, non-toxic materials to be durable, repairable, reusable, fully recyclable or compostable, and easily disassembled
	Shift funds and financial incentives to support a Circular Economy** over the harvesting and use of virgin natural resources
	Enact new incentives for cyclical use of materials, and disincentives for wasting
	Facilitate change in how end users' needs are met from "ownership" of goods to "shared" goods and provision of services
	Support and expand systems where product manufacturing considers the full life-cycle of their product in a way that follows the Zero Waste Hierarchy and moves towards more sustainable products and processes. Producers take back their products and packaging in a system that follows the Zero Waste Hierarchy.
	Identify and phase out materials that cause problems for Closed Loop Systems*
	Facilitate and implement policies and systems to encourage and support Local Economies*
	Re-consider purchasing needs and look for alternatives to product ownership
	Provide information to allow for informed decision-making
	Be aware of and discourage systems that drive needless consumption
Reduce	Plan consumption and purchase of perishables to minimize discards due to spoilage and non-consumption
	Implement Sustainable Purchasing** that supports social and environmental objectives as well as local markets where possible
	Minimize quantity and toxicity of materials used
	Minimize ecological footprint required for product, product use, and service provision
	Choose products that maximize the usable lifespan and opportunities for continuous reuse
	Choose products that are made from materials that can be easily and continuously recycled
	Prioritize the use of edible food for people
	Prioritize the use of edible food for animals
Reuse	Maximize reuse of materials and products
	Maintain, repair or refurbish to retain Value**, usefulness and function
	Remanufacture with disassembled parts; dismantle and conserve "spare" parts for repairing and maintaining products still in use
	Repurpose products for alternative uses
Recycle/ Compost	Support and expand systems to keep materials in their original product loop and to protect the full usefulness of the materials
	Maintain diversion systems that allow for the highest and best use of materials, including organics
	Recycle and use materials for as high a purpose as possible

	Develop resilient local markets and uses for collected materials wherever possible
	Provide incentives to create clean flows of compost and recycling feedstock
	Support and expand composting as close to the generator as possible (prioritizing home or on site or local composting wherever possible)
	Whenever home/decentralized composting is not possible, consider industrial composting, or if local conditions require/allow, anaerobic digestion
Recover	Maximize materials recovery from mixed discards and research purposes after extensive source separation
	If conditions allow, recover energy using only systems that operate at Biological Temperature and Pressure**
Residuals Management	Examine materials that remain and use this information to refine the systems to rethink, reduce, reuse, and recycle in order to prevent further discards
	Ensure minimization of impacts by means of biological stabilization of fermentable materials.
	Encourage the preservation of resources and discourage their Destructive Disposal or dispersal
	Plan systems and infrastructure to be adjusted as discards are reduced and its composition changes
	Minimize Gas Production and Release** and maximize gas collection
	Use existing landfill capacity and maximize its lifespan. Ensure it is Responsibly Managed.**
	Contain and control toxic residuals for responsible management
Unacceptable	Don’t support policies and systems that encourage the Destructive Disposal of organics and/or the destruction of recyclables
	Don’t support energy and Destructive Disposal systems that are dependent upon the continued production of discards
	Don’t allow the Incineration** of discards
	Don’t allow toxic residuals into consumer products or building materials

****Definitions:**

Biological Temperature and Pressure: The ambient temperature and pressure that occurs naturally without the use of added energy, or in any case not above 100C to change it such as anaerobic digestion

Circular Economy: An industrial economy that is, by design or intention, restorative and in which material flows are of two types, biological nutrients, designed to re-enter the biosphere safely, and technical nutrients, which are designed to circulate at high quality without entering the biosphere. Materials are consistently reused rather than discharged as waste

Closed Loop System: A system not relying on matter exchange outside of the system, as opposed to open loop where material may flow in and out of the system

Destructive Disposal: Discarded materials placed in a landfill or in an Incineration** facility

Diversion: An activity that removes a material from Destructive Disposal

Incineration: Incineration is a form of Destructive Disposal via combustion or thermal conversion/treatment, using temperatures above 100 degrees Celsius, of discarded materials into ash/slag, syngas, flue gas, fuel, or heat. Incineration includes facilities and processes that may be stationary or mobile, may recover energy from heat or power and may use single or multiple stages. Some forms of incineration may be described as resource recovery, energy recovery trash to steam, waste to energy, energy from waste, fluidized bed, catalytic cracking, biomass, steam electric power plant (burning waste), pyrolysis, thermolysis, gasification, plasma arc, thermal depolymerization or refuse derived fuel.

Minimize Gas Production and Release: This means keeping out source-separated organics as much as possible and biologically stabilizing the materials that go into landfill. For existing landfill cells that already contain unstabilized organics, the gas production should be minimized by keeping out rainwater and not recirculating leachate. Minimize methane release by permanently capping closed cells with permanent covers and installing gas collection systems within months of closure (not years). Maintain high suction on collection wells and do not damp down wells or rotate off the wells to stimulate methane production. Filter toxins in the gas into a solid medium that is containerized and stored on site. Note that this is not considered a renewable energy.

Problematic for a Closed Loop System: Materials that make it hard to recycle or compost the materials themselves or other materials. These may be contaminants for a material (like some forms of biodegradable plastics or stickers on fruit and vegetables) or materials that clog processing systems (like plastic bags).

Responsibly Managed Landfills: Manage landfills to minimize discharges to land, water or air that are a threat to planetary, human, animal or plant health. This must include plans for closure and financial liability.

Sustainable Purchasing: The purchase of goods and services that take into account the economic value (price, quality, availability and functionality) and the related environmental and social impacts of those goods and services at local, regional, and global levels.

Value: The importance, worth, or usefulness of something that may be economic, social, environmental, or sentimental.

(ZWIA, 2013)